June 2004

Science & Technology Review

National Nuclear Security Administration's
Lawrence Livermore National Laboratory

JASPER Gas Gun Has Plutonium in Its Sights

Also in this issue:

- The Era of Terascale Supercomputing
- Beryllium "Rainstorm" A Novel Cleanup Strategy
- Analyzing Interplanetary Dust Particles

About the Cover

This July marks the first anniversary of the first shot of the JASPER (Joint Actinide Shock Physics Experimental Research) two-stage gas gun located at the Department of Energy's Nevada Test Site. Since then, scientists have obtained data showing how plutonium, a key component of nuclear warheads, behaves under extreme pressures and temperatures. The article beginning on p. 4. describes how the successful results from the gas-gun experiments are strengthening scientists' ability to determine that the nation's nuclear stockpile is safe and reliable. Shown on the cover is an artist's rendering of the JASPER gas gun.

Cover illustration: Michael Loomis

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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Diagnosing disease before symptoms

A new national security research initiative at the Laboratory aims to rapidly diagnose infection one to two days after exposure to a pathogen, rather than waiting days to weeks for symptoms to appear. This approach to disease detection, called "pathomics," is the focus of a multimillion-dollar Livermore research effort that spans seven directorates and many disciplines. Pathomics is, in effect, the study of the molecular basis of infectious disease. It focuses on the changes in protein levels and other molecules that occur when a body has been exposed to a pathogen.

"The premise of pathomics is that before the onset of illness, there is a molecular indication of disease in human blood," explains project co-leader Fred Milanovich and founder of the Laboratory's Chemical and Biological National Security Program. Faster disease detection, followed by more rapid treatment, could help save the lives of people exposed to bioterrorist agents such as anthrax and plague. Ken Turteltaub, who is also a project co-leader, says, "We are focusing on the national security aspects of this technology. We want to be able to move from the discovery of a disease signature to its use in the country's national biodefense architecture."

So far, Laboratory researchers have identified four analytic techniques for pathomics that together should provide nearly comprehensive measurements of the protein and RNA content of blood samples.

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Discrepancies found in seismic hazard estimates

A five-year collaborative research project initiated and directed by François Heuze, a geotechnical engineer at Livermore, has determined that current methods for estimating the ground-shaking effects of major earthquakes could underestimate their severity. The results of this pioneering study of earthquake hazards at three University of California (UC) campuses—Santa Barbara (UCSB), Riverside (UCR), and San Diego (UCSD)—were reported in the April 2004 issue of *Soil Dynamics and Earthquake Engineering*.

The researchers found wide discrepancies between their own seismic hazard estimates for the three campuses and those produced by current estimating techniques used for designing new buildings and retrofitting existing buildings. "The biggest weakness in the current state of the practice for seismic hazard assessment," says Ralph Archuleta, professor of seismology at UCSB, "is that we have very little data for very large earthquakes where the site is close to the causative fault." UCSB, UCR, and UCSD all have major faults that are close to the campus.

"A single estimate of ground motion for a site is not appropriate," says Heuze. "Even if you have a known fault and restrict your calculations to a known magnitude, this fault could provide that magnitude in many different fashions. Thus, the severity of the ground shock where you stand could vary widely." To overcome this problem, the researchers placed several seismic monitoring stations at each campus in boreholes up to 100 meters deep and collected data on small earthquakes from local faults as well as regional seismic events. They tested soil samples at various depths and simulated hundreds of possible earthquake scenarios based on such variables as where a rupture might occur on the fault, the path it might travel, and how fast it might move. Because the soil may not behave in a linear fashion under very strong shaking, the researchers used nonlinear soil dynamics computer models to calculate the surface ground motions created by fault ruptures.

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Measuring stratospheric ozone in the upper troposphere

A team of scientists has identified a new method to measure the amount of stratospheric ozone that is present at any given time in the upper troposphere. Working with researchers from the National Oceanic Atmospheric Administration, the University of Colorado, the Jet Propulsion Laboratory, the National Center for Atmospheric Research, the National Aeronautics and Space Administration's Ames Research Center, and Harvard University, Livermore atmospheric scientists Cyndi Atherton and Dan Bergmann successfully quantified ozone as it is transported from the stratosphere down to the troposphere. The research is presented in the April 9, 2004, issue of *Science*.

Scientists within Livermore's Atmospheric Science Division created a computer model that can simulate how both ozone and hydrogen chloride (HCl) in the stratosphere travel downward through the tropopause and into the upper troposphere. Atherton and Bergmann used this model to simulate specific atmospheric events. These results, when compared to measurements, validated a novel technique that uses HCl to better understand the contribution of the stratosphere to upper-tropospheric ozone concentrations.

"This research shows that there are times when a significant amount of the ozone found in the upper troposphere was due to stratosphere-to-troposphere transport events," says Atherton. "Using this measurement method will lead to a better understanding of how much of this material is transported to the upper troposphere, where it affects climate and the chemical balance of the atmosphere." Until now, no experimental technique could reliably quantify stratospheric ozone in the upper troposphere.

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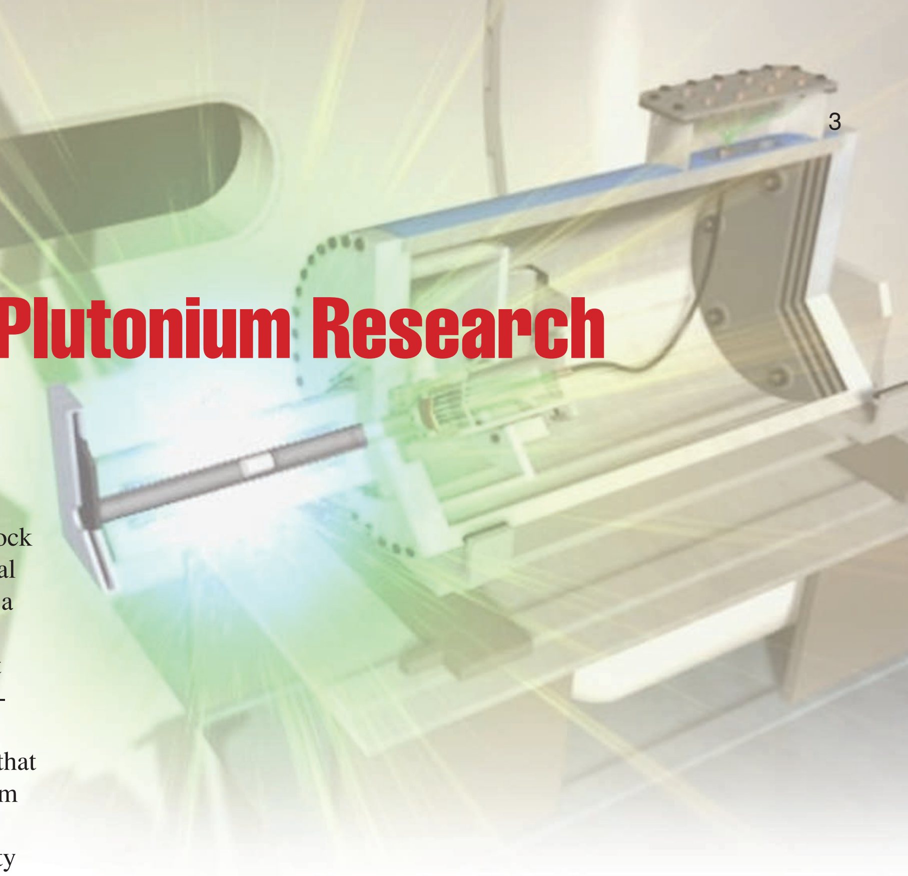
A New Era in Plutonium Research



NEXT month marks the first anniversary of the first "hot" shock experiment at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility at the Nevada Test Site. Last July, a team of engineers and physicists hunched intently over digital displays, watching the arrival of data so accurate and precise that they realized a new era of plutonium research had begun. "JAS-021" was the culmination of years of design, construction, and regulatory hurdles. Since last July, JASPER has fired six shots that have begun to experimentally map out the behavior of plutonium at the high pressures obtained when a nuclear weapon goes off.

JASPER, a two-stage gas gun that largely duplicates a facility at Livermore, fires projectiles at up to 8 kilometers per second into precisely fabricated plutonium targets, producing pressures up to 600 gigapascals. At these extreme conditions, experiments at the JASPER Facility achieve unprecedented accuracy, better than 1 percent. A suite of diagnostics measures the response of the target, directly yielding fundamental physics data—the equation of state—at these pressures for the most mysterious and complicated element.

Shock physics is a fundamental core competency at Livermore. The Shock Physics Group has made important contributions to a wide range of Laboratory programs since its formation in the 1960s. Over the years, the group has produced its share of scientific breakthroughs, including the first observation in 1994 of the elusive metallic phase of hydrogen, and most recently, determination of the melting point for iron in Earth's core, as reported in *Nature*. Today, this capability is key to science-based stockpile stewardship. JASPER's mission now includes a central role in the National Nuclear Security Administration's strategy for evaluating the effects of aging on the nuclear stockpile. Understanding the behavior of plutonium at extreme conditions, particularly its equation of state, is one of the program's highest priorities.

The success of JASPER is a striking reminder of the important role of experimental science and facilities aimed at basic physics in maintaining confidence in the nation's nuclear stockpile. It sometimes seems that stockpile stewardship is primarily a simulation activity enabled by increasingly powerful computers, such as the Advanced Simulation and Computing (ASC) machines. However, the massive simulations of nuclear weapons require the properties of plutonium as input, and precise measurements remain the essential source for these data.

Exploring high-pressure physics using gas guns is nothing new. It's a well-established, time-tested technique; in fact, it is just the thing to rely on when it comes to ensuring the nuclear stockpile. The arrival of JASPER allows us to routinely apply this technique to plutonium, a material never short on surprises.

The JASPER Facility is one element of a suite of new capabilities that together mark a renaissance in plutonium research under the auspices of stockpile stewardship. In addition to the shock data from JASPER, at least three additional milestones have been posted during this past year. At the Advanced Photon Source at Argonne National Laboratory, a consortium of researchers from Lawrence Livermore, Argonne, the University of Nevada, and the Carnegie Institute of Washington completed and commissioned a beam line devoted to static high-pressure physics. Shortly after "first light," Livermore scientists found the first evidence of a new high-pressure structure of plutonium that had been long predicted. Another team of Livermore researchers working at the European Synchrotron Radiation Facility in Grenoble made the first measurements of phonons in plutonium, providing a unique and crucial constraint on the interatomic potentials that underlie computer simulations of equations of state. (See *S&TR*, January/February 2004, pp. 12–14.) And those simulations took a major step forward this past year when Livermore physicists performed the first ab initio, fully quantum-mechanical molecular dynamics simulation for any actinide metal, in this case uranium, using the Q machine at Los Alamos National Laboratory.

■ William H. Goldstein is associate director of Physics and Advanced Technologies.

Shocking Plutonium to Reveal Its Secrets

A new two-stage gas gun at the Nevada Test Site is helping scientists better understand the behavior of plutonium.

ONE of the most daunting scientific and engineering challenges today is ensuring the safety and reliability of the nation's nuclear arsenal. To effectively meet that challenge, scientists need better data showing how plutonium, a key component of nuclear warheads, behaves under extreme pressures and temperatures. On July 8, 2003, Lawrence Livermore researchers performed the inaugural experiment of a 30-meter-long, two-stage gas gun designed to obtain those data. The results from a continuing stream of successful experiments on the gas gun are strengthening scientists' ability to ensure that the nation's nuclear stockpile is safe and reliable.

The JASPER (Joint Actinide Shock Physics Experimental Research) Facility at the Department of Energy's (DOE's) Nevada Test Site (NTS) is home to the two-stage gas gun. In the gun's first test, an unqualified success, Livermore scientists fired a projectile weighing 28.6 grams and traveling about 5.21 kilometers per second when it impacted an extremely small (about 30-gram) plutonium target. This experiment marked the culmination of years of effort in facility construction, gun installation, system integration, design reviews, and federal authorizations required to bring the experimental facility online.

Ongoing experiments have drawn enthusiastic praise from throughout DOE, the National Nuclear Security Administration (NNSA), and the scientific community. NNSA Administrator Linton Brooks said, "Our national laboratories now have at their disposal a valuable asset that enhances our due diligence to certify the nuclear weapons stockpile in the absence of underground nuclear weapons testing."

Bruce Goodwin, associate director of Livermore's Defense and Nuclear Technologies Directorate, said, "I am proud of the team effort that has produced the successful JASPER shots. I have personal appreciation for the extraordinarily challenging nature of plutonium. The precise data generated by these gas-gun experiments will open up our scientific understanding of plutonium."

Mark Martinez, Livermore's JASPER test director, notes that the experimental results have been so good they are generating significant interest in accelerating the test schedule. "The JASPER data are demonstrating superb quality and indicate that JASPER will meet its intended goal of generating high-precision plutonium data," he says.

JASPER was built at a total cost of about $20 million and sited in existing aboveground buildings at NTS. The facility was developed by personnel from Lawrence Livermore, Los Alamos, and Sandia

The JASPER Facility is located at the Department of Energy's Nevada Test Site, about 105 kilometers northwest of Las Vegas. The facility is housed in three buildings previously used to support Los Alamos National Laboratory's nuclear test program.

national laboratories and Bechtel Nevada, the NTS prime contractor.

Gas Guns Well Established

A well-established experimental technique for determining the properties of materials at high pressures, temperatures, and strain rates is to use a gas gun to shock a small sample of material with a projectile traveling at high velocity and then diagnose the material's response. Lawrence Livermore's three two-stage gas guns have made important contributions to solving scientific puzzles in condensed-matter physics, geophysics, and planetary science. For example, in 1996, Livermore's largest two-stage gas gun produced metallic hydrogen for the first time. Recently, with experimental techniques that will be used at JASPER, this gas gun was also used to determine the melting point of iron at Earth's core.

Neil Holmes, chief JASPER scientist and head of Livermore's shock physics program, says that two advantages of a gas gun are its proven dependability and scientists' extensive experience with it. Lawrence Livermore has more than 40 years experience shocking materials with gas guns. "When the projectile hits the target, the pressure wave is as steady as it can be," says Holmes. "As a result, researchers can focus on the target and diagnostics rather than the gun's performance."

Scientists fire projectiles from the JASPER gas gun into plutonium targets equipped with instruments for measuring and recording data. The projectile's impact produces a shock wave that passes through the target in a millionth of a second or less, creating pressures of more than 600 gigapascals (6 million times the pressure of air at Earth's surface), temperatures to thousands of kelvins, and densities several times that of plutonium's original solid state.

The JASPER team's role in the Stockpile Stewardship Program is to measure the fundamental properties of plutonium. Data from the experiments are used to determine material equations of state, which express the relationship between pressure, density, and temperature. The equation of state is essential for generating reliable computational models of plutonium's behavior under weapons-related conditions. Knowledge of these properties is required to assess, without nuclear testing, the performance, safety, and reliability of nuclear weapons.

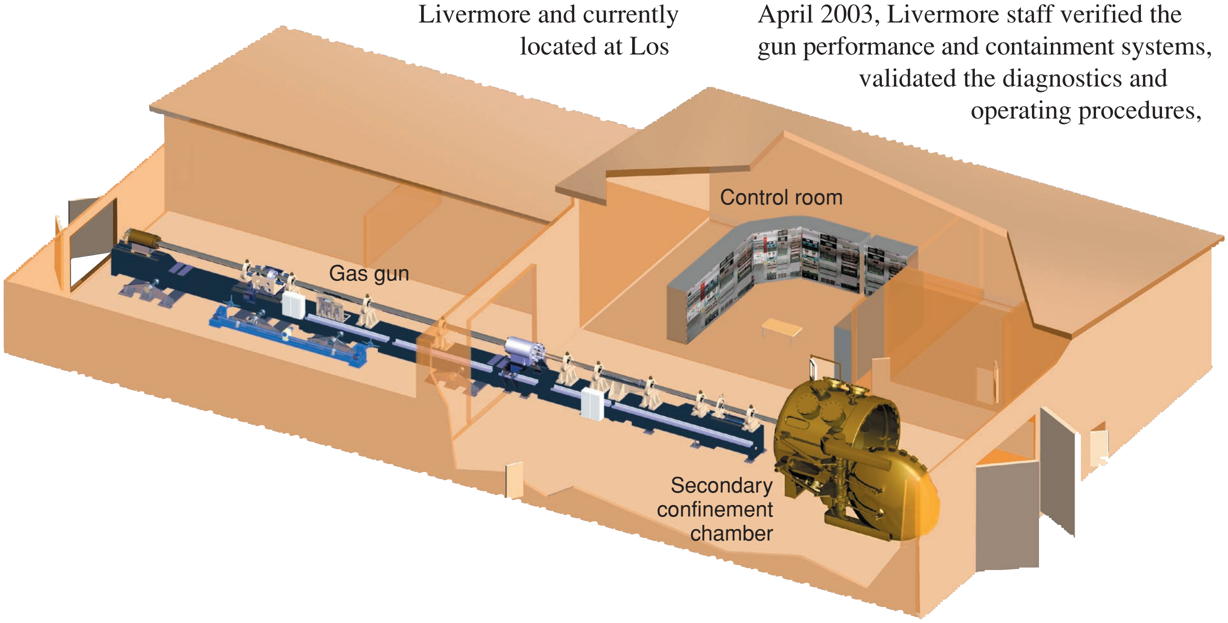
Long Qualification Phase

Prior to the construction of JASPER, the only facility available for performing shock tests on plutonium was the 40-millimeter, single-stage gas gun built at Livermore and currently located at Los Alamos. This gun can achieve a maximum projectile velocity of about 2 kilometers per second and up to 30 gigapascals of pressure.

Researchers determined that much higher projectile velocities were needed to achieve the desired conditions for plutonium research. Two-stage, light gas guns similar to the JASPER gun have been operational at Lawrence Livermore, Los Alamos, and Sandia national laboratories for many years, but they are not licensed to perform experiments on plutonium.

In the late 1990s, it was recognized that a new two-stage gas-gun facility dedicated to plutonium research, and located in a remote location, could provide valuable data on plutonium's equations of state. Ideally, the facility would operate with a short turnaround time between shots and at a modest cost per shot. In early 1998, a study conducted by a team of scientists and engineers from several national laboratories identified the Able Site at NTS as the best location. The site's three main buildings had previously been used by Los Alamos's nuclear test program.

Construction and facility modifications at the Able Site started in April 1999 and were completed in September 1999. The JASPER gas gun was installed in early 2000, and the first system-integration demonstrations were completed in September 2000. From February 2001 to April 2003, Livermore staff verified the gun performance and containment systems, validated the diagnostics and operating procedures,



JASPER's two-stage gas gun, seen in this artist's depiction, measures 30 meters long and includes a secondary confinement chamber that encloses the primary target chamber.

and fulfilled the regulatory and compliance requirements. As part of the validation process, researchers fired a series of 20 shots using nonnuclear materials to qualify the gun for use with nuclear materials. At the conclusion of the installation project, JASPER managers received NNSA Defense Programs Excellence and DOE Project Management awards.

Livermore operates the facility for NNSA, and Bechtel Nevada supplies resources for facility maintenance and operation, and diagnostic design and operation.

JASPER Gun Matches Livermore's

The JASPER gas gun was designed to match the internal dimensions of the large two-stage gas gun at Livermore, which has been operational since 1972. By copying that design, researchers took advantage of the extensive database and experience that exists from using the Livermore gun, thereby minimizing the effort required to characterize the JASPER gun at start-up. Although the internal dimensions are the same, JASPER's containment system is significantly more complex because the Laboratory's gas gun is not used with hazardous materials such as plutonium and, hence, does not require a special material-confinement system. (See the box on p. 8.) The Livermore gas gun serves as a test bed for developing techniques and training personnel for future experiments at JASPER. "We work out JASPER experiments first on our two-stage gun at Livermore with nonnuclear materials," says Martinez.

JASPER's gas gun is driven first with gunpowder and then with a light gas. In the first stage, hot gases from the gunpowder propellant drive a 4.5-kilogram plastic deformable piston down a pump tube. The piston compresses a light gas, typically hydrogen, as it travels down the narrowing tube. This gas, which is the second-stage driving medium, is compressed until it builds up enough pressure to burst a valve. The explosive gas accelerates a 15- to 30-gram projectile down the launch tube toward the target at a velocity of up to 8 kilometers per second. (See the figure on p. 9.)

The projectile is made of plastic with a flat, metal plate embedded in its face to directly impact the plutonium target. Depending on the desired shock pressure, the metal plate is made of aluminum, tantalum, or copper. A typical projectile measures 28 millimeters in diameter and weighs 25 grams.

The speeding projectile enters the primary target chamber (PTC), which houses the plutonium target. Just prior to entering the PTC, the passing projectile is sensed by a continuous x-ray source and detector, which

The two-stage gas gun at the JASPER Facility in Nevada fired its first shot in July 2003. Livermore operates the facility for the National Nuclear Security Administration. Bechtel Nevada supplies resources for facility maintenance and operation, and diagnostic design and operation.

Electronics project engineer John Warhus monitors preparations for a gas-gun experiment from the JASPER control room.

trips a switch that triggers the detonation of the ultrafast closure valve. This valve effectively traps radioactive debris within the PTC following the projectile's impact on the plutonium target.

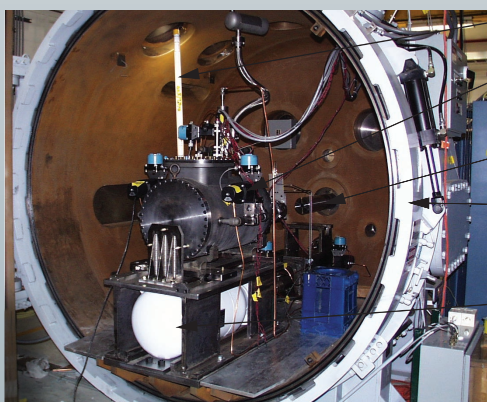
When the projectile hits the plutonium target, the impact produces a high-pressure shock wave of about 600 gigapascals. The temperature, a critical variable in a material's equation of state, can reach as high as 7,000 kelvins. By comparison, the surface of the Sun is about 5,800 kelvins. The destroyed plutonium target is contained within the PTC. Following the experiment, the PTC is discarded and sent to the federal Waste Isolation Pilot Plant in New Mexico.

Projectile velocities are precisely determined by experimental parameters such as the type and amount of gunpowder, the driving gas, the diameter of the barrel, and the mass of the projectile. JASPER facility manager Ben Garcia notes that as a precaution, all shots are first simulated using gun performance codes on computers. "We want to make sure we don't produce any pressures that could exceed the design limits of the gun," he says.

Confining Plutonium Is Central to JASPER Gas-Gun Design

Livermore engineers adopted a dual-layered approach for JASPER's two-stage gas gun to ensure that plutonium dust or fragments are not released into the building or the environment after each experiment. The two layers are the primary target chamber (PTC) and the secondary confinement chamber. The PTC, which houses the plutonium target, is designed to contain target material under worst-case conditions following impact with the speeding projectile. The PTC is discarded after every shot and shipped to the federal Waste Isolation Pilot Plant in New Mexico.

Lead PTC engineer Matt Cowan notes that designing the PTC has been a challenge because of the dynamic loading of the PTC during a shot. "We anticipated two potential failure modes in the PTC: loads that cause a rupture in the pressure vessel and loads that cause a dynamic gap at the sealing surfaces."



The primary target chamber, which houses the plutonium target, is designed to contain target material under worst-case conditions. It is located inside the secondary confinement chamber. Other key features inside the secondary confinement chamber include the flash x ray for measuring projectile velocity, the continuous x ray for tripping the ultrafast closure valve, and the high-explosive gas accumulator for trapping gases after the ultrafast closure valve has been tripped.

The engineers conducted extensive modeling to determine where plutonium debris would be distributed inside the PTC following impact with a projectile. In addition, experiments using plutonium surrogates provided valuable experience in refining the design of the PTC. For example, researchers applied a layer of phosphorous-32, which has a two-week half-life, to a gold target because radioactive materials are easier to detect if they escape from the PTC. Debris shields were added to absorb some of the momentum of high-velocity impacts and to protect critical O-rings that seal the PTC's interior. "JASPER experiments cause particulates to fly everywhere at extremely high speeds, so we need to protect O-rings from the sandblasting effect," explains Cowan. Engineers also expanded the volume of space around the target impact plane.

Livermore's High Explosives Applications Facility (HEAF) was used to demonstrate the PTC's design limits. The testing at HEAF created explosive forces about 150 percent of the predicted dynamic loads that the PTC would experience with plutonium targets. The data from HEAF agreed with results from simulations and strengthened the engineers' confidence that plutonium would be contained.

The PTC's ultrafast closure-valve system at the chamber's entrance was designed and manufactured by Ktech Inc. (Albuquerque, New Mexico), and adapted for use on JASPER by Livermore engineers. The valve closes a 1.3-centimeter-diameter aluminum tube in about 60 microseconds by detonating 90 grams of high explosives wrapped around the tube. The valve then traps plutonium debris within the PTC. "A splash-back of plutonium travels at the same speed as the projectile, so we need to close the tube extremely quickly," says Cowan.

The PTC is located in the secondary confinement chamber, which has a large circular door to access the PTC. The secondary chamber ensures that any material that might escape from the PTC will not migrate into the building. "The secondary chamber is not expended after a test," says Cowan, "and it is not significantly challenged during a shot."

As a final precaution, radiation-control technicians, fully suited with respirators and radiation detectors, enter the gas-gun building following every shot to make sure the plutonium debris has been fully contained within the PTC.

Currently, the major diagnostic instruments are two flash x-ray units, which measure projectile velocity to within 0.1 percent accuracy, and electrical pins, which measure the speed of the shock wave from the impact of the projectile. The facility also has the capability to use a Velocity Interferometer System for Any Reflector (VISAR), a tool that measures the velocity of the exploding target by recording Doppler-shifted reflected light. These data are essential to understanding plutonium's material properties. Additional diagnostic instruments are planned that will measure the temperature, electrical conductivity, and other characteristics of the target after impact.

Targets Made at Livermore

The first series of JASPER experiments used plutonium targets nicknamed "top hats," which consist of a plutonium disk the size of a half dollar bonded to a smaller, nickel-size disk of plutonium. The top hat design was first proven on Livermore's two-stage gas gun with copper, aluminum, and tantalum disks.

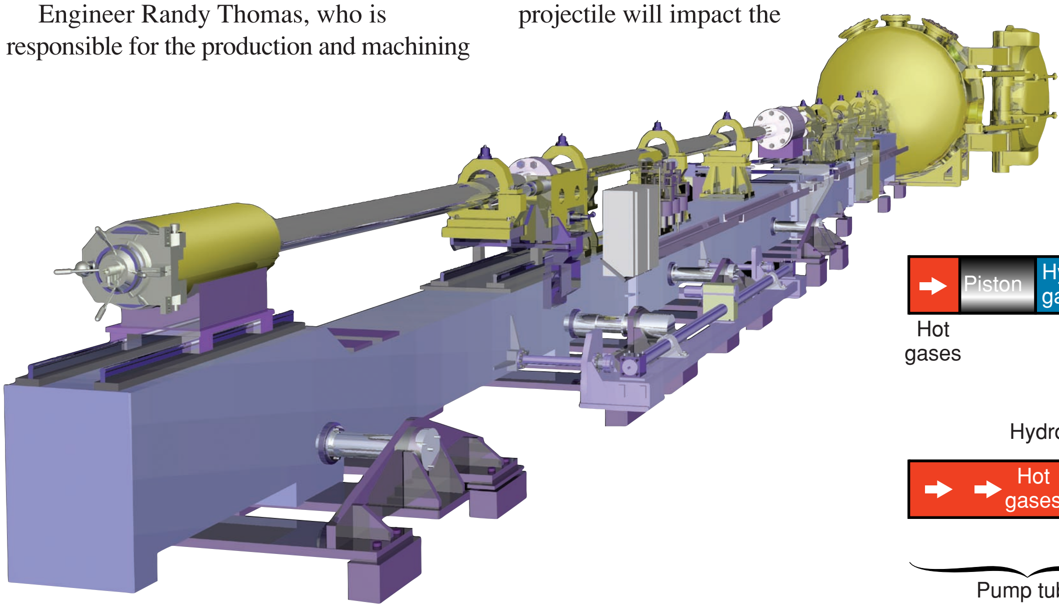
Engineer Randy Thomas, who is responsible for the production and machining of JASPER targets at Livermore, notes the top hat targets must meet extremely precise requirements: flat to within 2.5-millionths of a meter with the two faces of each disk parallel to each other within 2.5-millionths of a meter. Meeting such tight tolerances requires a complex and time-consuming production and machining process. Plutonium is first cast into a cylinder using a graphite mold. The resulting cylinder is sliced into disks and then heated to eliminate internal stress. The disks are rolled with specific orientations to obtain correct metallurgical properties, heated again, and machined until they are within less than 1 percent of their final dimensions. Then the disks are checked for the correct density and radiographed to detect any voids and inclusions. Even slight imperfections result in the plutonium target being unusable. The disks undergo final machining and inspection to ensure they are flat and parallel. Then they are bonded together.

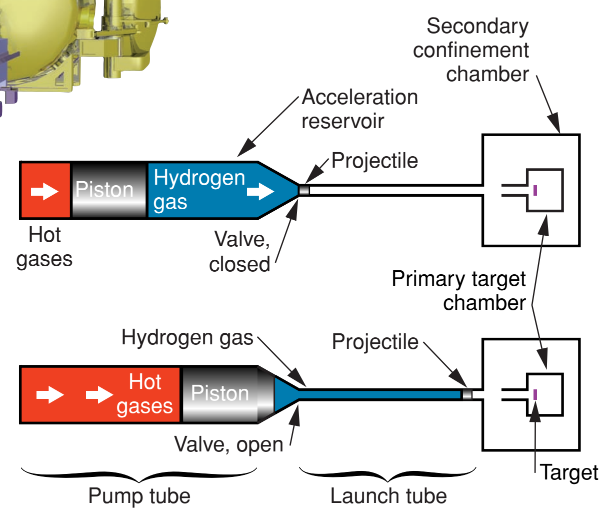
After final measurement and characterization, the plutonium is loaded into the target assembly. The assembly is aligned beforehand so that the projectile will impact the target at its exact center. The target assembly is leak tested, backfilled with an inert atmosphere, placed in a federally approved shipping container, and trucked to NTS. Holmes describes the final product as, "The highest quality plutonium samples we've ever seen. That quality reflects the superb plutonium fabrication and machining capabilities at Livermore."

The top hat plutonium target uses 13 diagnostic electrical-shorting pins mounted on its surface: 6 on the large disk, 6 on the small disk, and 1 that fits through a hole in the middle of the smaller disk. On impact from the projectile, a shock wave travels through the base plate and electrically shorts the pins. The velocity of the shock front passing through the target is calculated using the measured shock arrival times from the shorting pins and the known target thickness. The pins' orientations allow for correcting the effects of projectile tilt during target impact.

Data for Equations of State

Livermore scientists are excited about the experimental results. "The JASPER gas gun





A schematic showing how a two-stage gas gun operates. In the first stage, hot gases from the powder propellant drive a piston, which compresses the hydrogen gas in the pump tube. In the second stage, the high-pressure gas ruptures the valve, accelerating the projectile down the launch tube toward the target.

has validated itself as an important tool for plutonium shock physics. Everything has worked as planned," says Holmes. "We're thrilled with the quality of data. These experiments have never before been done on plutonium with this accuracy."

Each JASPER experiment provides one data point on plutonium's Hugoniot curve. The Hugoniot is derived from conservation of mass, momentum, and energy equations using experimental values of projectile velocity (flash x-ray data) and shock velocity (electrical pin data). Hugoniot curves are then used to develop material equation-of-state models used in weapon performance calculations.

"Equation of state is one of the most important elements in building a robust capability for predicting weapon performance," says Holmes. "We mainly use theoretical equations of state for our simulations. That's not sufficiently accurate for stockpile stewardship purposes. We need data that will either validate our theories or force changes in them."

JASPER experiments complement the subcritical nuclear materials experiments that Livermore scientists have conducted underground at NTS since 1997. (See *S&TR*, July/August 2000, pp. 4–11.) Those experiments use high explosives to blow apart tiny amounts of plutonium but stop short of nuclear chain reactions. These complex hydrodynamic experiments provide vital information on the behavior and performance of aging nuclear materials.

The gas gun allows scientists to study plutonium over a broader range of conditions than is the case with subcritical experiments. Moreover, gas-gun technology eliminates uncertainties introduced by high-explosive-driven experiments. Holmes points out that gas-gun experiments can generate distortions in projectiles, but the distortions are always the same shape and are readily accounted for.

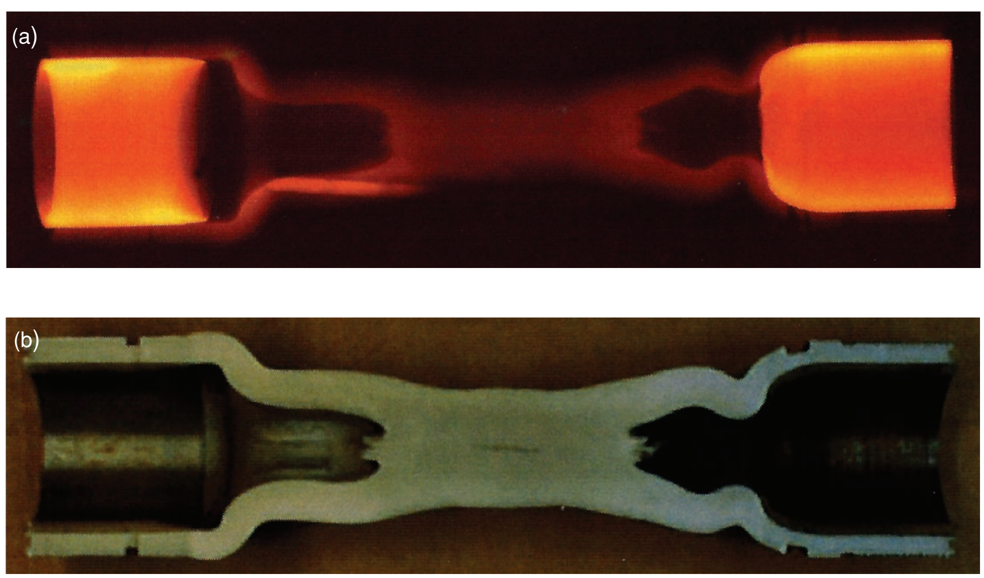
An extrudable piston is shown before and after firing. The piston compresses hydrogen gas in the first stage of the two-stage gas gun.

Future Directions

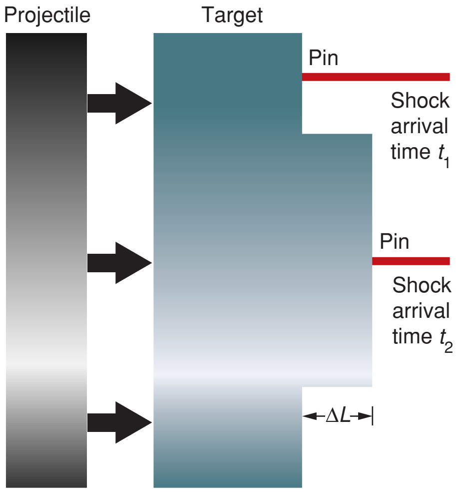
The early experimental successes have generated significant discussion regarding how to schedule more experiments and how to extract more data from each experiment.

To meet the increasing demand for experiments, the JASPER team is exploring ways to increase the number of experiments scheduled from the current 12 per year. For example, a glove box (required for safe handling of plutonium) has been commissioned at the Device Assembly Facility (DAF) at NTS, located about 15 kilometers from JASPER. Livermore managers are planning to ship plutonium samples from Livermore to DAF for final bonding and placement in the target assembly to support a busier schedule. Using DAF would also decrease the risk of damage from transporting finished plutonium targets and diagnostics over a long distance.

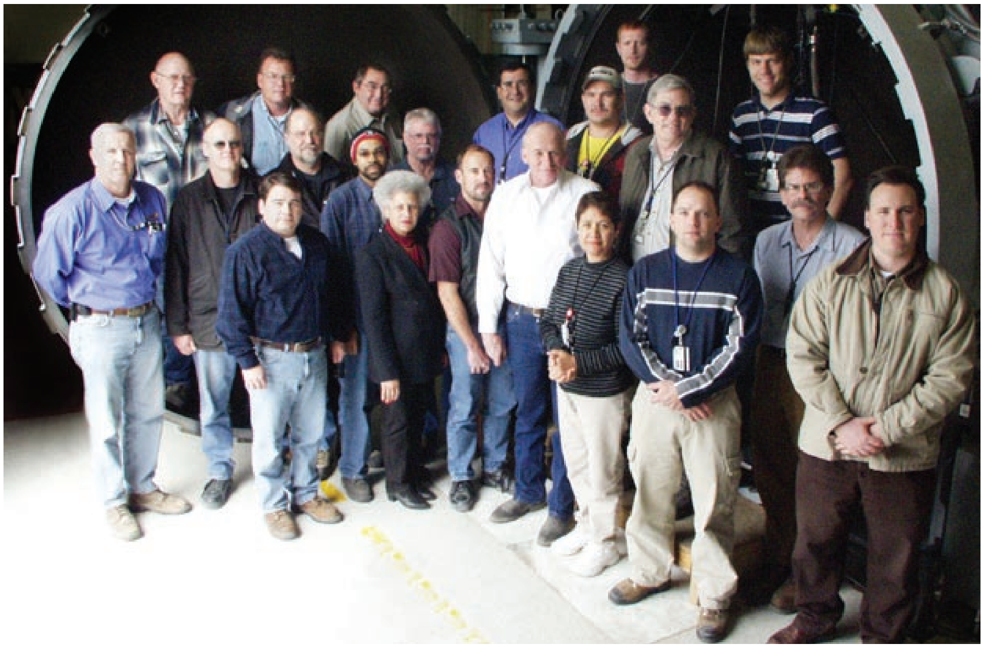
New diagnostics are being considered to generate additional information about the physical processes occurring in shocked plutonium. For example, plans are under way to measure electrical and thermal conductivity as well as sound



(a) An x ray and (b) a photograph show the ultrafast closure valve after it detonates to prevent any plutonium debris from escaping from the primary target chamber.



Electrical pins on the target measure the velocity of the shock front as it passes through the target material. Velocity is determined by dividing the difference in pin position (ΔL) by the difference in shock arrival time ($t_1 - t_2$).



The JASPER Facility team from Lawrence Livermore and Bechtel Nevada.

speeds of shocked plutonium targets. The optical properties of the shocked target—the light emitted during an experiment—will also be studied using lasers.

Another set of experiments being planned would test aged plutonium to determine if its shocked properties are different from newly cast material. At the same time, physicists and engineers are looking at new projectile designs, such as those made of different densities, to obtain specific shock pressures. Martinez recalls how Livermore personnel once predicted, "If we build it (JASPER), they will come." He notes that physicists at Los Alamos are designing a series of experiments, as are colleagues from Britain's Atomic Weapons Establishment. In fact, about 10 years of shots are already in the planning stages. Martinez says, "People are getting new ideas all the time to find out more about plutonium with JASPER."

—Arnie Heller

Key Words: Device Assembly Facility, equation of state, gas gun, Hugoniot curve, Joint Actinide Shock Physics Experimental Research (JASPER) Facility, Nevada Test Site (NTS), plutonium, stockpile stewardship, Velocity Interferometer System for Any Reflector (VISAR).

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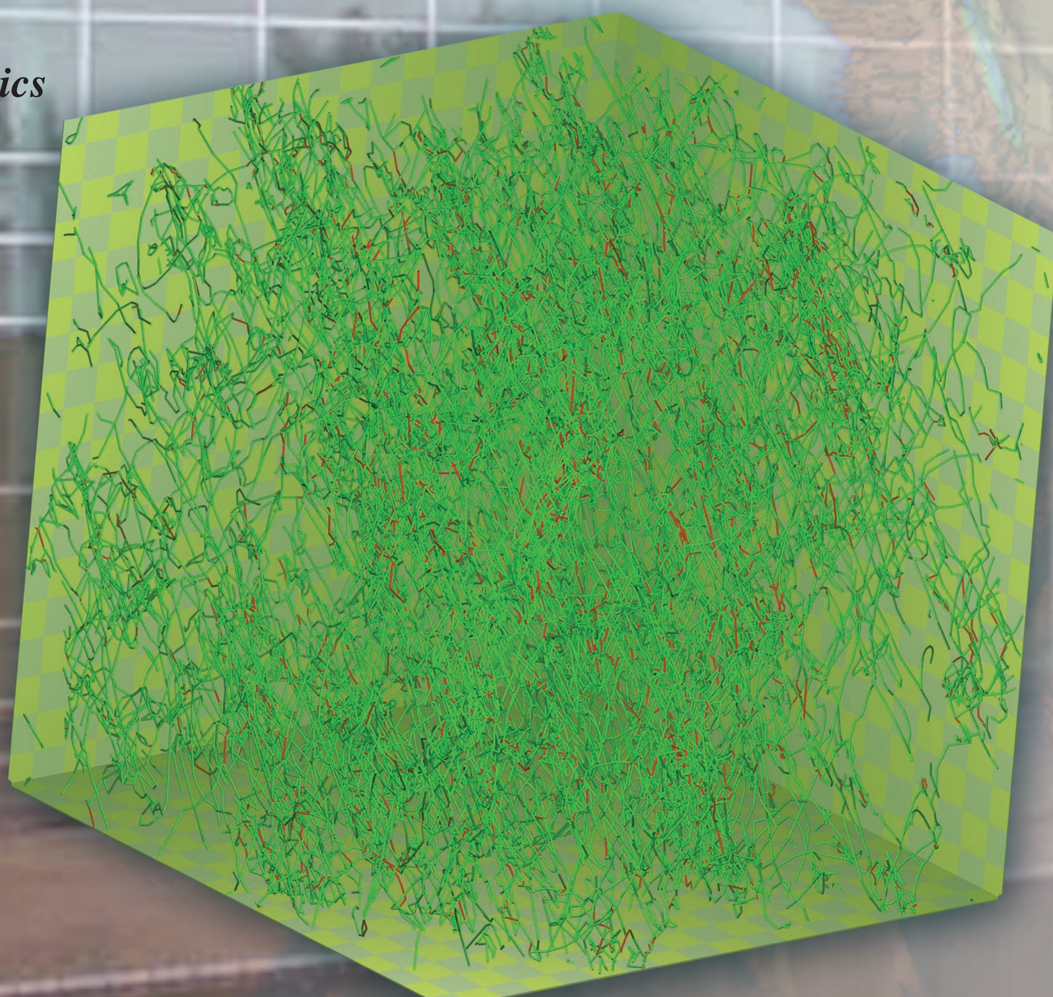
Strategic Supercomputing Comes of Age

As ASC supercomputers settle into the terascale regime and prepare for petascale, simulations reveal new physics insights to scientists.



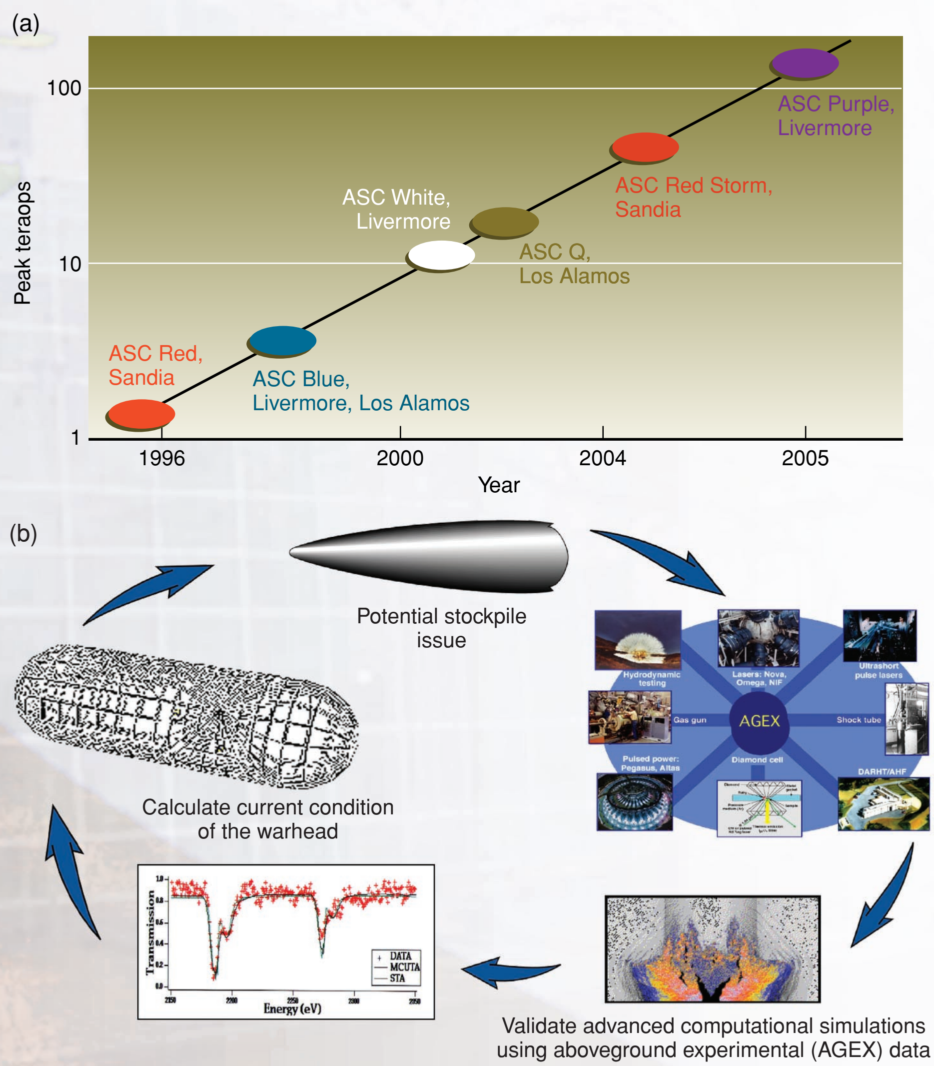
As the National Nuclear Security Administration's (NNSA's) Advanced Simulation and Computing (ASC) Program prepares to move into its second decade, the users of ASC's enormous computers also prepare to enter a new phase. Since its beginning in 1995, the ASC Program (originally the Accelerated Strategic Computing Initiative, or ASCI) has been driven by the need to analyze and predict the safety, reliability, and performance of the nation's nuclear weapons and certify their functionality—all in the absence of nuclear weapons testing. To that end, Lawrence Livermore, Los Alamos, and Sandia national laboratories have worked with computer industry leaders such as IBM, Intel, SGI, and Hewlett Packard to bring the most advanced and powerful machines to reality.

But hardware is only part of the story. The ASC Program also required the development of a computing infrastructure and scalable, high-fidelity, three-dimensional simulation codes to address issues related to stockpile stewardship. Most important, the laboratories had to provide proof of principle that users could someday have confidence in the results of the simulations when compared with data from legacy codes, past nuclear tests, and nonnuclear science experiments.

Efforts are now successfully moving beyond that proof-of-principle phase, notes Randy Christensen, who leads program planning in the Defense and Nuclear Technologies (DNT) Directorate and is one of the founding members of the tri-laboratory ASC Program. Christensen says, "With the codes, machines, and all the attendant infrastructure in order, we can now advance to the next phase and focus on improving the physics models in our codes to enhance our understanding of weapons behavior." Livermore's 12.3-teraops (trillion operations per second) ASC White machine and Los Alamos's 20-teraops ASC Q machine are in place, and the next systems in line are Sandia's 40-teraops ASC Red Storm and Livermore's 100-teraops ASC Purple. "In anticipation of ASC Purple in 2005, we are shifting our emphasis from developing parallel-architecture machines and codes to improved weapons science and increased physics understanding of nuclear weapons," adds Christensen. "We are taking the next major step in the road we mapped out at the start of the program."

A Long and Winding Road

"Ten years ago, we were focused on creating a new capability, and the program was viewed more as an experiment or an initiative," says Mike McCoy, acting leader for DNT's ASC Program. "Many skeptics feared that the three-dimensional codes we were crafting, and the new machines we needed to run them on, would fail to be of use to the weapons program." These skeptics had three areas of concern: First, would the new three-dimensional codes be useful? That is, would the code developers, working with other scientists, be able to develop new applications with the physics, dimensionality,



(a) The first seven years of the Accelerated Strategic Computing Initiative focused on creating a new capability for the Stockpile Stewardship Program, including the demonstration of three-dimensional applications. ASC Purple, slated to arrive in 2005, is the "entry point" for conducting high-fidelity, full weapons system simulations. (b) Over the next 10 years, the focus will be on using those capabilities as an integral part of the Stockpile Stewardship Program and on improving predictive capabilities.

resolution, and computational speed needed to take the next step in predictivity? Second, would the computers be reliable and work sufficiently well to grind through the incredibly complex and detailed calculations required in a world without underground nuclear testing? Third, would the supporting software infrastructure, or simulation environment, be able to handle the end-to-end computational and assessment processes? For that first decade, the program's primary focus was on designing codes and running prototype problems to address these concerns.

"Sophisticated weapon simulation codes existed before the ASC and Stockpile Stewardship programs," says Christensen. "However, because of the limited computer power available, those codes were never expected to simulate all the fine points of an exploding nuclear weapon. When the results of these simulations didn't match the results of the underground tests, numerical 'knobs' were tweaked to make the simulation results better match the experiments. When underground nuclear testing was halted in 1992, we could no longer rely so heavily on tweaking those knobs."

At the time that underground testing ceased and NNSA's Stockpile Stewardship Program was born, Livermore weapons scientists were depending on the (then) enormous machines developed by Seymour Cray. Cray designed several of the world's fastest vector-architecture supercomputers and introduced closely coupled processors. "We had reached the limits on those types of systems," says McCoy, who is also a deputy associate

Not Just Computers and Codes: Making It All Work

Designers and physicists in the tri-laboratory (Livermore, Los Alamos, and Sandia national laboratories) Advanced Simulation and Computing (ASC) Program are now using codes and supercomputers to delve into regimes of physics heretofore impossible to reach. What made these amazing tools possible were the efforts of the computer scientists, mathematicians, and computational physicists who brought the machines and the codes to the point of deployment.

It wasn't easy. Throughout the era of testing nuclear weapons, approximations were a given for the computations. When calculations produced unusual results, scientists assumed that lack of resolution or faithful replication of geometry or faithful physics models or some combination were the culprits. "It was assumed that, no matter how big the machines were at that time, this inaccuracy would remain a given," says Mike McCoy, deputy associate director of Livermore's Computation Directorate. "But this concern was greatly mitigated, because testing provided the 'ground truth' and the data necessary to calibrate the simulations through the intelligent use of tweaking 'knobs.'"

When testing was halted, the nation's Stockpile Stewardship Program came into being. Scientists now needed to prove that computer simulation results could hold their own and provide valuable information, which could be combined with data from current experiments and from underground tests to generate the necessary insights.

To bring such parity to computer simulations in the triumvirate of theory, experiment, and simulation, code designers had to address three concerns. First, could supercomputing hardware systems be built to perform the tasks? Second, could a workable simulation environment or support infrastructure be created for these systems? Third, could the mathematical algorithms used in the physics codes be scalable?

Bringing on the Hardware

The move to massively parallel processing supercomputers in the late 1980s was followed by the cessation of underground testing of nuclear devices in 1992 and the start of science-based stockpile stewardship. The ASC Program required machines that could cost-effectively run simulations at trillions of operations per second (teraops) and use the terabytes of memory needed to properly express the complexity of the physics being simulated. This requirement forced a jump to massively parallel processing supercomputers that were, above all, scalable. In other words, these machines needed to be able to run large problems across the entire system without bogging down from communication bottlenecks, which led to the development of high-performance interconnects and the necessary software to manage these switches. Demands on hardware grew, and now the ASC Program at Livermore juggles three technology curves to ensure that users will have the machines they need today, tomorrow, and in the future. (See *S&TR*, June 2003, pp. 4–13.)

Creating an Infrastructure

Without a proper infrastructure, the ASC systems are little more than hard-to-program data-generation engines that create mind-numbing quantities of intractable, raw data. The infrastructure (sometimes called the supporting simulation environment) is what makes the terascale platform a real tool. The infrastructure includes improved systems software, input and output applications, message-passing libraries, storage systems, performance tools, debuggers, visualization clusters, data reduction and rendering algorithms, fiber infrastructure to offices, assessment theaters, high-resolution desktop displays, wide-area networks with encryption, and professional user consulting and services at the computer center—all focused on making the machines and codes run more efficiently.

The infrastructure has evolved in balance with the hardware. In 1999, for example, 2 terabytes of data from a three-dimensional simulation might have taken 2 or 3 days to move to archival storage or to a visualization server. By the end of 2000, that journey took 4 hours. Today, those 2 terabytes can zip from computer to mass storage in about 30 minutes. Similar efficiency and performance improvements have director in the Computation Directorate. “From there, we ventured into scalar architecture and the massively parallel world of ASC supercomputers—systems of thousands of processors, each with a large supply of local memory. We were looking at not only sheer capability—which is the maximum processing power that can be applied to a single job—but also price performance. We were moving away from specialized processors for parallel machines to commodity processor systems and aggregating enough memory at reasonable cost to address the new complexity and dimensionality.”

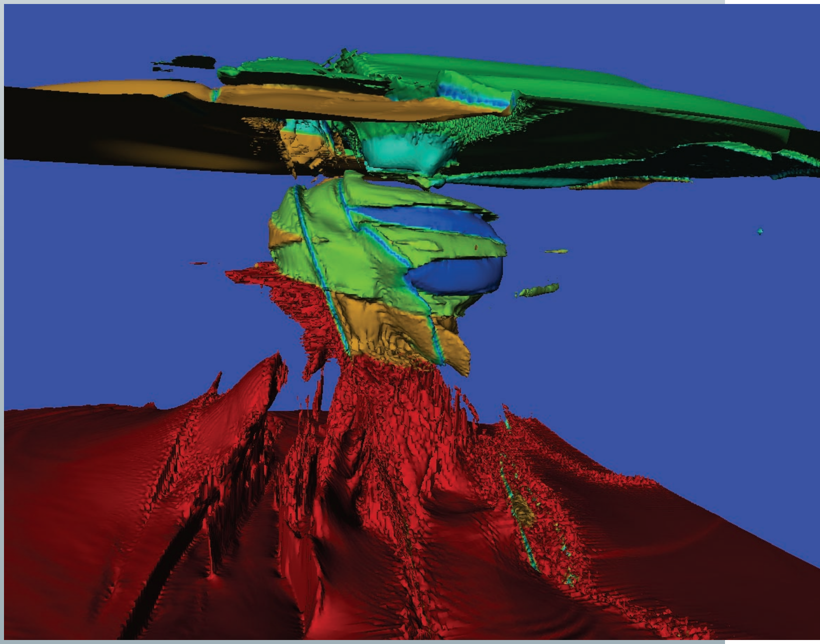
The challenge was to move into the world of massively parallel ASC systems in which thousands of processors may be working in concert on a problem. “First, we had to learn how to make these machines work at large scale,” says McCoy. “At the same time, we were developing massively parallel multiphysics codes and finding a way to implement them on the new machines. It was a huge effort in every direction.”

As the machines matured, the codes matured as well. “We’ve entered the young adult years,” says McCoy. “ASC White is running reliably in production mode, with a mean time to failure of a machine component measured in days, not hours or minutes. The proof-of-principle era is ending: The codes are deployed, the weapon designers increasingly are using these applications in major investigations, and this work is contributing directly to stockpile stewardship. With the upcoming 100-teraops ASC Purple, we believe that in many cases where we

occurred with compilers, debuggers, file systems, and data management tools as well as visualization and distance computing. Remote computing capabilities within the tri-laboratory community are easily available to all sites.

Designing Codes and Their Algorithms

Over the past few years, the ASC Program has developed some very capable three-dimensional codes and has maintained or further developed supporting science applications and two-dimensional weapons codes. Because of the enormous size of the computers and their prodigious power consumption, notes McCoy, the applications themselves are generally ignored by the media in favor of headline-producing computers. But if the truth were known, it is these codes and the people who build them, not the computers, that are the heart and soul of the ASC Program. “The computers come, and after a few years, they go,” says McCoy. “But the codes and code teams endure.” The greatest value of the ASC Program resides in these software assets, and this value is measured in billions of dollars. The backbone of these scientific applications is mathematical equations representing the physics and the numerical constructs to represent the equations. To address issues such as how to handle a billion linear and nonlinear equations with a billion unknowns, computational mathematicians and others created innovative linear solvers (*S&TR*, December 2003, pp. 17–19) and Monte Carlo methods (*S&TR*, March 2004, pp. 19–21) that allow the mathematics to “scale” in a reasonable manner. Thus, as the problem grows more complex, processors can be added to keep the solution time manageable.



This composite image is taken from a three-dimensional simulation performed to help scientists better understand the sequence of events that led to the containment failure of the Baneberry underground test in December 1970. The complex geologic features of the Baneberry Event show pressure contours superimposed on geologic layers and faults. The different colors define different geologic material, including Paleozoic rock, tuff, and alluvium. The two turquoise lines slanting diagonally upward are faults that, scientists believe, contributed significantly to the containment failure. This simulation was the largest of its kind, requiring about 40 million zones, 3,000 times steps, and 40,000 processing hours on the Laboratory’s Multiprogrammatic Capability Resource machine, and created about 3 terabytes of data that had to be stored and interpreted.

have good experimental data, numerical error will be sufficiently reduced to make it possible to detect where physics models need improvement. We have demonstrated the value of high-resolution, three-dimensional physics simulations and are now integrating that capability into the Stockpile Stewardship Program, as we work to improve that capability by enhancing physics models. The ASC Program is no longer an initiative, it's a permanent element of a tightly integrated program with a critical and unambiguously defined national security mission."

Looking forward, Jim Rathkopf, an associate program leader for DNT's A Program, notes that with the arrival of Purple, codes will be able to use even higher resolution and better physics. "Higher resolution and better physics are required to reproduce the details of the different phases of a detonation and to determine the changes that occur in weapons as they age and their materials change over time."

Predicting Material Behavior

It's exciting times for scientists in the materials modeling world. The power of the terascale ASC machines and their codes is beginning to allow physicists to predict material behavior from first principles—from knowing only the quantum mechanics of electrons and the forces between atoms. Earlier models, which were constrained by limited computing capabilities, had to rely on averages of material properties at a coarser scale than the actual physics demanded.

Elaine Chandler, who manages the ASC Materials and Physics Models Program, explains, "We can now predict very accurately the elastic properties of some metals. We're close to having predictive models for plastic properties as well."

Equation-of-state models are also moving from the descriptive to the predictive realm. It's possible to predict melt curves and phase boundaries from first principles and to predict changes in the arrangement of atoms from one crystalline structure to another. For example, scientists are running plasticity calculations to look at how tantalum moves and shears, then conducting experiments to see if their predictions are correct. Using this process, they can determine basic properties, such as yield strength.

With the older descriptive modeling codes, scientists would run many experiments in differing regimes of temperature and pressure, then basically "connect the dots" to find out what a metal would do during an explosion. Now, they can perform the calculations that provide consistent information about the entire process. "It's a new world," says Chandler, "in which simulation results are trusted enough to take the place of physical experiments or, in some cases, lead to new experiments."

In the future, ASC Purple and the pioneering BlueGene/L computer will contribute to this new world. BlueGene/L is a computational-science research and evaluation machine that IBM will build in parallel with ASC Purple and deliver in 2005. According to Chandler, BlueGene/L should allow scientists to reach new levels of predictive capability for processes such as dislocation dynamics in metals, grain-scale chemical reactions in high explosives, and mixing in gases. Chandler says some types of hydrodynamics and materials science calculations will be relatively straightforward to port to the BlueGene/L architecture, but others, particularly those involving quantum-mechanical calculations,

(a) When the Cray-1 machine was installed in 1981, it was one of the fastest, most powerful scientific computers available. The last Cray obtained by Lawrence Livermore, in 1989, had 16 central processing units and about 2 megabytes of memory. (b) Nearly a decade later, the massively parallel 10-teraops ASC White arrived at the Laboratory as part of the National Nuclear Security Administration's Advanced Simulation and Computing Program. (For more on the history of supercomputing at Livermore, see *S&TR*, March 2002, pp. 20–26.)

Leaping from Milestone to Milestone

With the birth of the Stockpile Stewardship Program (SSP), the need for better computer simulations became paramount to help ensure that the nation's nuclear weapons stockpile remained safe, reliable, and capable of meeting performance requirements. The tri-laboratory (Livermore, Los Alamos, and Sandia national laboratories) Advanced Simulation and Computing (ASC) Program was created to provide the integrating simulation and modeling capabilities and technologies needed to combine new and old experimental data, past nuclear-test data, and past design and engineering experience. The first decade was devoted to demonstrating the proof of principle of ASC machines and codes. As part of that effort, the program set up a number of milestones to "prove out" the complex machines and their advanced three-dimensional physics codes.

The first milestone, accomplished in December 1999 by Livermore researchers on the ASC Blue Pacific/Sky machine, was the first-ever three-dimensional simulation of an explosion of a nuclear weapon's primary (the nuclear trigger of a hydrogen bomb). The simulation ran a total of 492 hours on 1,000 processors and used 640,000 megabytes of memory in producing 6 million megabytes of data contained in 50,000 computer files. The second Livermore milestone, a three-dimensional simulation of the secondary (thermonuclear) stage of a thermonuclear weapon, was accomplished in early 2001 on the ASC White machine—the first time that White was used to meet a milestone.

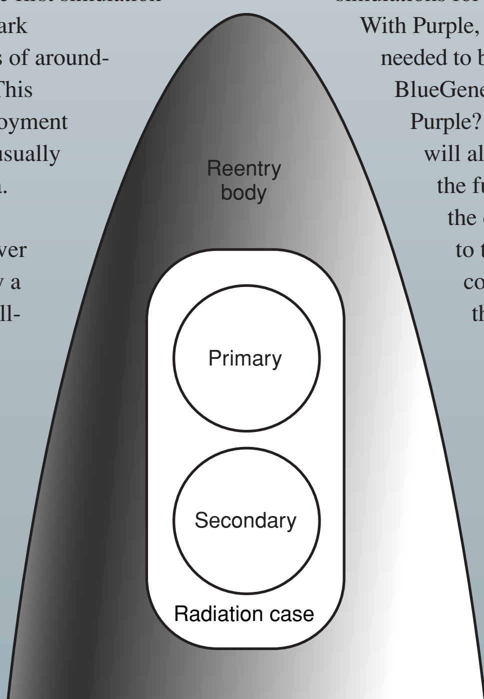
Livermore met a third milestone in late 2001, again using ASC White, coupling the primary and secondary in the first simulation of a full thermonuclear weapon. For this landmark simulation, the total run time was about 40 days of around-the-clock computing on over 1,000 processors. This simulation represented a major step toward deployment of the simulation capability. The quality was unusually high when compared to historic nuclear-test data. A detailed examination of the simulation results revealed complex coupled processes that had never been seen. In 2001, ASC White was also used by a Los Alamos team to complete an independent full-system milestone simulation.

In December 2002, Livermore completed another milestone on ASC White when a series of two-dimensional primary explosion calculations was performed. These simulations exercised new models intended to improve the physics fidelity and quantified the effect of increased spatial resolution on the accuracy of the results. The first production version of this code was also released at this time to users. Yet another Livermore team used ASC White to perform specialized three-dimensional simulations of a critical phase in the operation of a full thermonuclear weapon.

In 2003, Livermore teams completed separate safety and performance milestones. For the performance milestone, one team worked remotely on the ASC Q machine at Los Alamos to conduct a suite of three-dimensional primary explosion simulations in support of a Life Extension Program (LEP). Moving even farther from proof-of-principle demonstration and closer to deployment, a code team worked with the LEP team to accomplish this milestone, which addressed complex technical issues and contributed to meeting SSP objectives.

"We accomplished major objectives on time—with the early milestones demonstrating first-of-a-kind proof-of-principle capabilities," says Tom Adams, an associate program leader for DNT's A Program. "Achieving these milestones was the result of an intense effort by the code teams, who were assisted by dedicated teams from across the Laboratory. ASC milestones have now transitioned from these early demonstrations to milestones focused on improving the physics fidelity of the simulations and supporting stockpile stewardship activities. We are now in the position of delivering directly to the SSP."

Adams adds that the upcoming ASC Purple machine is a significant entry point. "Purple is the fulfillment of one of the original goals of the ASC Program, which is to bring a 100-teraops system to bear on stockpile stewardship issues. We need Purple to perform full, three-dimensional simulations for stockpile stewardship on a business-as-usual basis. With Purple, we'll have the computing power and the codes needed to begin to address challenges in detail. Similarly, BlueGene/L will extend material models." And, beyond Purple? Petaops (quadrillion operations per second) systems will allow weapons designers and other users to address the fundamental underlying sources of uncertainty in the calculations. The goal is to be prepared to respond to technical issues that might arise because of compontent aging or new material requirements in the stockpile.



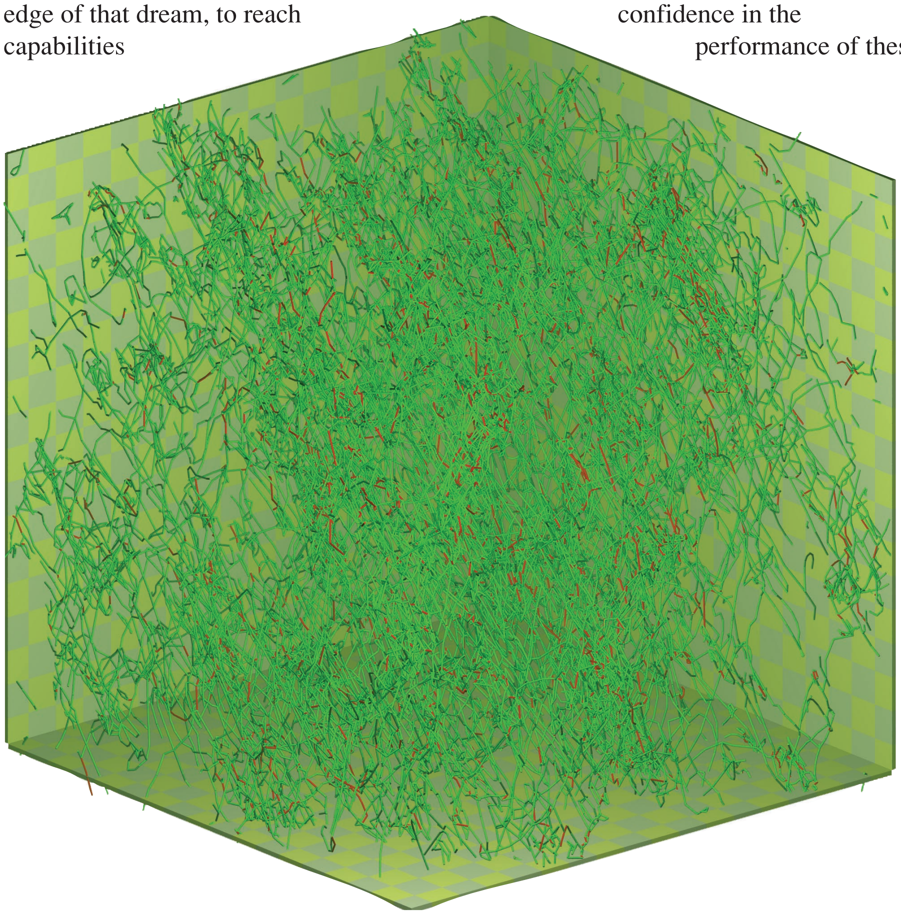
In thermonuclear weapons, radiation from a fission device (called a primary) can be contained and used to transfer energy for the compression and ignition of a physically separate component (called a secondary) containing thermonuclear fuel.

will require significant restructuring in order to use the architecture of this powerful machine. This is a challenge well worth the effort, because of the unprecedented computer power that BlueGene/L will offer to attack previously intractable problems.

"Nearly a half century ago," adds Chandler, "scientists dreamed of a time when they could obtain a material's properties from simply knowing the atomic numbers of the elements and quantum-mechanical principles. That dream eluded us because we lacked computers powerful enough to solve the complex calculations required. We are just now able to touch the edge of that dream, to reach the capabilities needed to make accurate predictions about material properties."

Delivering the Goods

ASC simulations play a key role in stockpile assessments and in programs to extend the life of the nation's arsenal. Each year, a formal assessment reports the status of the nation's stockpile of nuclear warheads and bombs. (See *S&TR*, July/August 2001, pp. 4–10.) This process involves the three national weapons laboratories working in concert to provide a "snapshot" of the stockpile's health. Together, Livermore and Los Alamos are developing an improved methodology for quantifying confidence in the performance of these nuclear systems, with the goal of fully integrating this methodology into these annual assessments. The new methodology, known as quantification of margins and uncertainties (QMU), draws together information from simulations, experiments, and theory to quantify confidence factors for the key potential failure modes in every weapons system in the stockpile. (See *S&TR*, March 2004, pp. 19–21.)



A snapshot of dislocation microstructure generated in a massively parallel dislocation line dynamics simulation. The simulation was performed using the new code ParaDiS, developed at Livermore. ParaDiS has reached several computational milestones and outperformed all other existing codes by more than an order of magnitude in terms of computational complexity (that is, number of dislocation lines) and the magnitude of simulated plastic strain.

The assertion that the nuclear explosive package in a weapon performs as specified is based on a design approach that provides an adequate margin against known potential failure modes. Weapons experts judge the adequacy of these margins using data from past nuclear experiments, ground and flight tests, and material compatibility evaluations during weapons development as well as routine stockpile surveillance, nonnuclear tests, and computer simulations. With the cessation of underground nuclear testing, the assessment of these margins relies much more heavily on surveillance and computer simulations than in the past and therefore requires the simulations to be more rigorous and detailed.

Because no new weapons are being developed, the existing ones must be maintained beyond their originally planned lifetimes. To ensure the performance of these aging weapons, Livermore and Los Alamos weapons scientists use QMU to help them identify where and when they must refurbish a weapons system. When needed, a Life Extension Program (LEP) is initiated to address potential performance issues and extend the design lifetime of a weapons system through refurbishment or replacement of parts. For the W80 LEP now under way, results from ASC simulations are weighed along with data from past nuclear weapons tests and from recent small-scale science tests. These results will support certification of the LEP.

Using today's ASC computer systems and codes, scientists can include unprecedented geometric fidelity in addressing issues specific to life extension. They can also investigate particular aspects, such as plutonium's equation of state, scientifically and in detail, and then extend that understanding to the full weapons system. The results of these simulations, along with data from legacy testing and current experiments, improve the ability of weapons designers to make sound decisions in the absence of nuclear testing.

As computational capability increases, designers will have a more detailed picture of integrated weapons systems and can address even more complex issues—for example, how various materials fracture—with even higher resolution.

Right Answers for Right Reasons

Even as inaccuracies due to mathematics and numerics are being resolved by running simulations at ever higher resolutions, the question remains: If a simulation result is unusual, how do scientists know whether it is a problem due to inadequate resolution or simply an error, or bug, in the coding?

According to Cynthia Nitta, manager of the ASC Validation and Verification (V&V) Program, an effort was established by the ASC Program to rigorously examine the computational science and engineering simulation results with an eye to their credibility. "Can we trust that the results of simulations are accurate? Do the results reflect the real-world phenomena that they are striving to re-create or predict?" asks Nitta. "In the V&V Program, we are developing a process that should increase the confidence level for decisions regarding the nation's nuclear stockpile. Our methods and processes will establish that the calculations provide the right answers for the right reasons."

The verification process determines whether a computer simulation code for a particular problem accurately represents the solutions of the mathematical model. Evidence is collected to ascertain whether the numerical model is being solved correctly. This process ensures that sound software-quality practices are used and the software codes themselves are free of defects and errors. It also checks that the code is correctly solving the mathematical equations in the algorithms and verifies that the time and space steps or zones chosen for the mathematical model are sufficiently resolved.

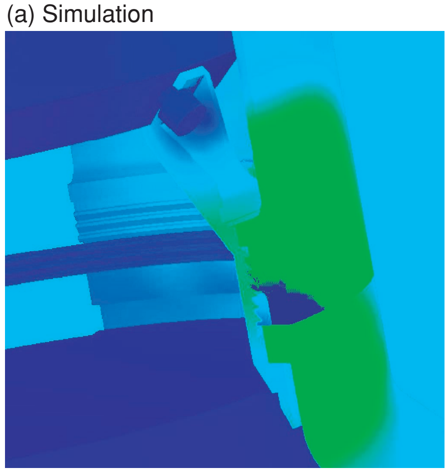
The validation process determines whether the mathematical model being used accurately represents the phenomenon being modeled and to what degree of accuracy. This process ensures that the simulation adequately represents the appropriate physics by comparing the output of a simulation with data gathered in experiments and quantifying the uncertainties in both.

Nitta says, "Computer simulations are used in analyzing all aspects of weapons systems as well as for analyzing and interpreting weapons-related experiments. The credibility of our simulation capabilities is central to the credibility of the certification of the nuclear stockpile. That credibility is established through V&V analyses."

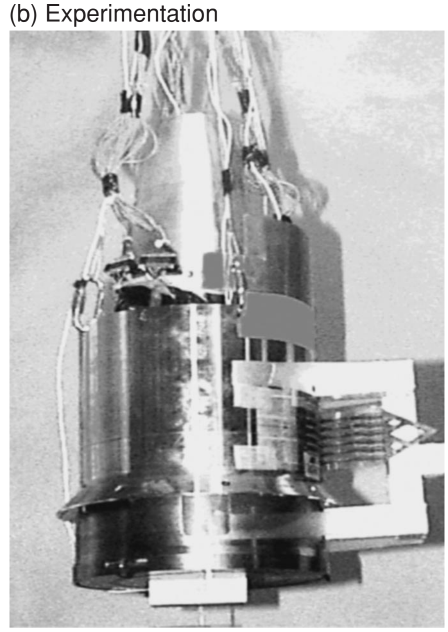
Terascale—A Beginning, Not an End

With the proof-of-principle phase ending and new codes being deployed, what does the future hold? With the arrival of the 100-teraops Purple in 2005, many simulations become possible, including a full-system calculation of a nuclear weapon with sufficient resolution to distinguish between phenomenological and numerical issues. But, as McCoy, Christensen, and

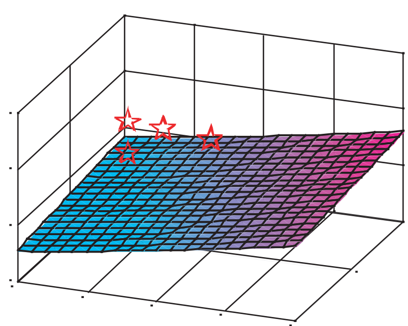
(a) Simulation



(b) Experimentation



(c) Quantitative comparison



The verification and validation (V&V) process ties together (a) simulations and (b) experiments using (c) quantitative comparisons.

The Terascale Simulation Facility (TSF) at Lawrence Livermore will have two machine rooms for housing ASC Purple and BlueGene/L. The 100-teraops Purple will be powered by 12,288 microprocessors (in 1,536 individual nodes) and have 50 terabytes of memory (400,000 times more capacity than the average desktop computer) and 2 petabytes of disk storage (the content of approximately one billion books). The facility also features substantial visualization areas, including theaters and laboratories to handle the extremely large data sets produced.

others point out, 100 teraops is just the beginning.

The ASC Program plans to increase the level of confidence in predictions that such simulations can bring as well as increase the predictive capability, by tying together simulations and experiments even more closely and quantifying the uncertainty of the simulated results.

"We're positioning our science codes to run on the Purple and BlueGene/L machines so that we can understand the physics in even greater detail," says Christensen. "It's been a challenging journey over the past decade: In the ASC Program, we've demonstrated that we can acquire and use the world's most powerful computers to perform three-dimensional calculations that capture many details of weapons performance. Now, we must look toward the next goal, which is to be able to predict weapons behavior and quantify the confidence we have in that prediction. If the past decade is any indication—and we believe it is—this is a goal we can, and will, indeed attain."

—*Ann Parker*

Key Words: Accelerated Strategic Computing Initiative (ASCI), Advanced Simulation and Computing (ASC) Program, ASC Purple, ASC White, BlueGene/L, descriptive models, Life Extension Program, materials modeling, predictive models, quantification of margins and uncertainties (QMU), Stockpile Stewardship Program (SSP), Verification and Validation (V&V) Program, weapons certification.

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A Bang-Up Job

Keeping Things Clean at the Contained Firing Facility

AMID rolling pastures 24 kilometers southeast of Lawrence Livermore's main site, the buildings and bunkers of the Laboratory's Experimental Test Site tuck neatly into fingers of canyons punctuated with coastal sage and blue oak. One's eye catches, perhaps, a jackrabbit, and the quiet of the landscape interweaves the tinkling song of a horned lark.

Three years ago, the site's new Contained Firing Facility (CFF) brought explosives tests indoors and minimized the dispersion of waste, providing more environmental protection than was previously possible in controlled open-air firing areas. Today, a new cleanup program developed for the CFF keeps the indoor firing chamber environment clean and maintains beryllium exposure well below established limits.

The Contained Firing Facility at Site 300 is situated in a remote area 24 kilometers southeast of Lawrence Livermore's main site.

New Standard, New Challenges

The CFF was designed to conduct nonnuclear high-explosive experiments in support of the nation's Stockpile Stewardship Program. When the CFF first fired up operations, a great challenge was born. In the shift from performing outdoor detonations, a firing environment was created that would contain hazardous materials in one confined spot, which, in turn, created the need for a novel cleanup effort never before undertaken.

Central to the cleanup effort is the mitigation of harmful effects from beryllium exposure. About every third shot fired at the CFF contains beryllium, a naturally occurring metal that is used in nuclear weapons because of its capacity as a highly effective moderator and reflector for neutrons. But, as good as beryllium is for nuclear reactions, in certain forms—namely, as an airborne particulate—it can be harmful to the health and safety of workers who come into regular contact with it.

Although Occupational Safety and Health Administration standards allow for a permissible exposure limit of 2 micrograms of beryllium per cubic meter per 8-hour period, the Department of Energy (DOE) has raised the bar an order of magnitude for its facilities. DOE mandates that a working environment remain below an "action level" of 0.2 microgram of beryllium per cubic meter per 8-hour period, regardless of respiratory protection used. At this level or above, worker protection provisions must be implemented. In addition, the goal of Livermore's Chronic Beryllium Disease Prevention Program is to keep exposure levels as far below the mandated action level as is practical.

Starting from Scratch

B Program's Site 300 facility manager Gordon Krauter and facility supervisor Jack Lowry worked with Livermore Hazards Control personnel to develop a protocol that would allow members of the CFF team to safely reenter the concrete firing chamber within a day of a detonation to retrieve experimental data and begin the cleanup procedure. The CFF team also needed access to the chamber between shots with minimal personal protective gear.

Working directly with the CFF team, Dave Zalk, an industrial hygienist, became convinced that to perform the tasks routinely done in the CFF, workers must be free to hear, speak, and move about in as unfettered a manner as possible. So the team was not content to establish a protocol that still required facility workers to don cumbersome self-contained breathing apparatus (SCBA) gear (gear that's similar to SCUBA equipment but is not for use underwater) or respirators when working in the chamber *after* cleanup. It was a tall order to fill.

To some, the prospect of reaching decontamination levels that allowed workers back into the chamber without a SCBA suit after a shot was unthinkable.

Water, Water Everywhere

In developing an optimal beryllium cleanup program, the Hazards Control team realized that water would be a major factor in the effort. Upon entering the chamber after a test shot, workers were surprised to find scattered puddles of water. They found that, by accident, the drainage conduit running the length of one of the chamber walls was not completely emptied of water before detonating the test shot. Also, the postshot levels of metals were a fraction of what they expected. This finding led to the development of the low-tech but highly effective technique to help mitigate the beryllium contamination of a blast.

The team placed large cardboard barrels in the chamber, filled them with water, and left them in the chamber to explode during the next shot. The resulting action was not entirely unlike an indoor rainstorm: The water in the barrels aerosolized, filled the volume of the chamber, and fell in droplets to the floor, capturing much of the particulate matter produced during the shot and depositing it in a thick layer of sludge on the chamber floor. Previously, the postshot environment consisted of fine dust clouds and particulate matter easily stirred up by workers entering the chamber. But the aftermath of this water explosion was an environment in which the fine particles of beryllium and other wastes were trapped in a layer of mud, which could be scooped up with snow shovels and then transferred to the appropriate containers for disposal at a federal hazardous waste facility.

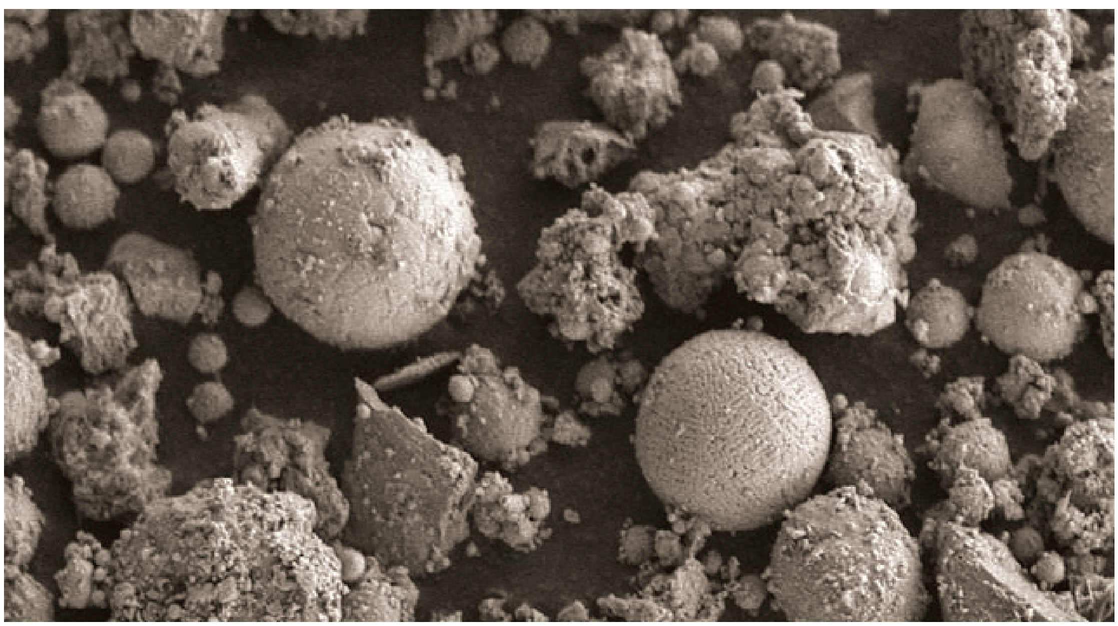
Water, Air, and . . . Hair Spray?

The three-pronged cleanup procedure that emerged as the preferred and most effective approach combines a purging of contaminated air, subsequent water washes in addition to the test shot's water blast, and a final finishing touch of hair spray. Yes—hair spray.

The first of the three steps involves a complete purging and filtering of the chamber air. The ventilation system, which is capable of 10 complete air changes per half hour, is run for 45 minutes before the 25-ton door to the firing chamber is opened. The exhaust gases from the purge are processed through a series of filters before being released to the atmosphere.

After the chamber is purged and observed for any live explosives, a CFF team wearing SCBA enters to collect the test data—a large cassette containing radiographic film that captures an image of the test material at the moment of implosion. Then the cleanup procedure, which can take up to several weeks, begins. A remotely operated oscillating washing apparatus is set up in the

A scanning electron microscope captures an image of mixed debris collected from the Contained Firing Facility's firing chamber after an experiment.



chamber, which is again sealed for the 15-minute water wash and scrub down. About 38,000 liters of recycled water later, the chamber is opened, and the team reenters to mop up. Water brooms, garden hoses, giant squeegees, and a large-capacity vacuum cleaner round out the technologies used in the procedure. "It's amazing how low-tech a solution this is to such a high-tech problem," observes hydrodiagnostic technician Keith Toon.

Because of the nature of beryllium, and the manner in which it is embedded in the nooks and crannies of the chamber walls from the force of the explosion, it is nearly impossible to remove all traces from the chamber. However, the CFF team found that the beryllium does not have to be removed from the walls to be rendered benign; it just has to be rendered immobile. As a result, the final cleanup step involves a spray application of an encapsulating solution that is similar in formula to hair spray. The solution coats and adheres to the chamber surfaces and keeps any errant beryllium particles stuck in place—until the next shot, anyway, at which time the encapsulant is knocked loose by the blast and the entire cleanup process begins again. Adding this final step shaves two weeks off the cleanup time and allows for more shots to be scheduled than was previously possible.

A Clean Sweep

Constant air monitoring at the CFF shows the results of the cleanup protocol are impressive. Concentration levels of beryllium are consistently below the mandated action level. "The success that we have achieved is a testament to the excellent teamwork between B Division and Hazards Control personnel," says Zalk.

While this massive effort may seem tedious at times, what it has offered—in addition to surpassing health guidelines—is peace of mind and a better working environment. Toon agrees. "Not having to always wear the SCBA suit has made working in this environment easier. We've got enough data now to better handle and control the beryllium. We take extra steps to make sure everything is safe. I definitely worry less."

Less worry for facility workers. Less hazardous waste for the songbirds and jackrabbits. That's something to sing about.

—*Maurina S. Sherman*

Key Words: beryllium, Chronic Beryllium Disease Prevention Program (CBDPP), Contained Firing Facility (CFF), Site 300.

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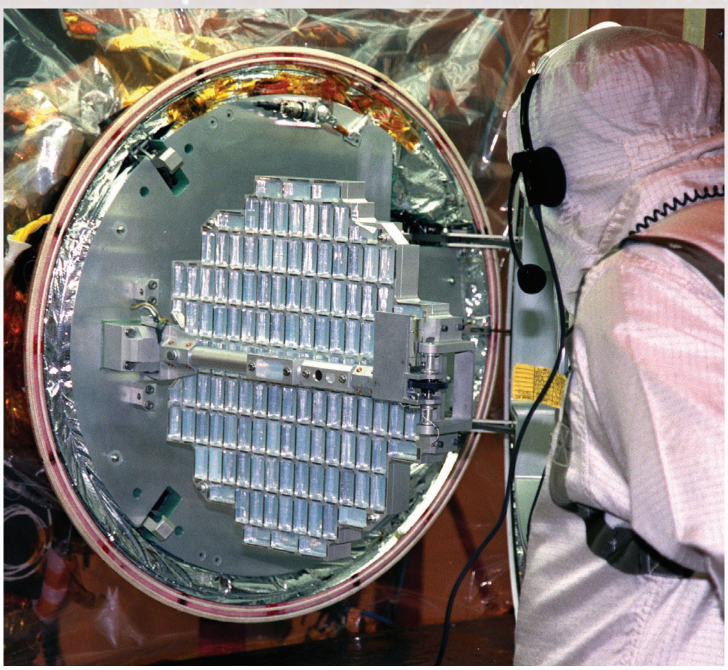
Two types of personal protective equipment are used at the Contained Firing Facility. The white suits shown above are worn for working outside the firing chamber and for performing dry operations in the chamber after cleanup. The brown suits are worn for wet operations (that is, cleaning and decontamination) inside the chamber.

Seeing the Universe in a Grain of Dust

IMAGINE traveling halfway to Jupiter—3.2 billion kilometers—for a small handful of comet dust. That's the mission for the National Aeronautics and Space Administration's (NASA's) Stardust spacecraft launched on February 7, 1999. This past January, Stardust flew by Comet Wild 2's nucleus and through a halo of gases and dust at the comet's head, collecting cometary dust particles released from the surface just hours before. In 2006, the spacecraft will deliver the less than 1 milligram of particles to Earth. A Lawrence Livermore team is perfecting ways to extract and analyze the tiny particles using its new focused-ion-beam instrument and SuperSTEM, a scanning transmission electron microscope.



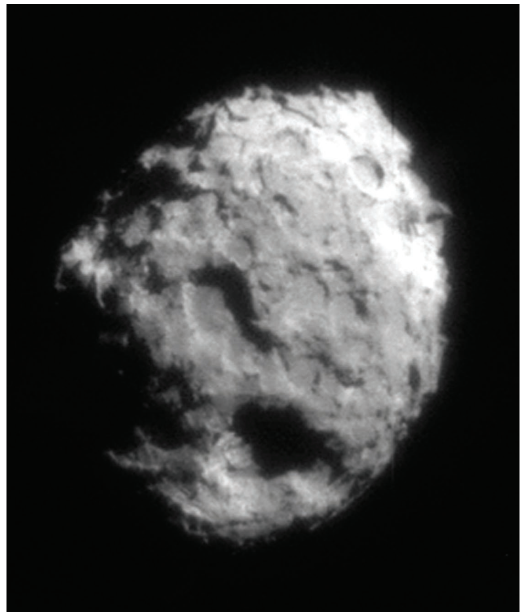
The Stardust spacecraft's collector grid, which is filled with aerogel, was designed to capture particles from Comet Wild 2 as the spacecraft flew through the comet's dust and gas cloud in January 2004. Because the aerogel is composed of 99 percent air, it can collect and store fast-moving dust particles without damaging them.

Stardust is the first NASA space mission dedicated solely to collecting comet dust and will be the first to return material from a comet to Earth. Comets are the oldest and most primitive bodies in the solar system. They are formed from frozen gas, water, and interstellar dust and may have brought water to Earth, making life possible. Wild 2—pronounced "Vilt 2" after the name of its Swiss discoverer—was formed with the Sun and the rest of the solar system 4.5 billion years ago. For billions of years, it has circled the Sun in the Kuiper Belt, a region beyond the orbit of Neptune. Scientists think comets from this region have escaped the warming, vaporization, and collisions that have altered matter in the inner solar system. Unlike Halley's Comet, which has been altered as a result of orbiting the Sun for a long time, Wild 2's pristine composition is expected to offer a rich source of information about the solar system's potential building blocks.

As the 5-meter-long Stardust spacecraft traveled through Wild 2's dust and gas cloud, to within about 100 kilometers of the comet's nucleus, particles were captured in the spacecraft's collector grid. The 1,000-square-centimeter grid is filled with the silica-based material aerogel, whose lightness minimizes damage to the grains as they encounter the spacecraft at a speed of about 21,000 kilometers per hour—or six times faster than a bullet. In the late 1980s, Livermore scientists developed an aerogel made up of 99 percent air, making it ideal for NASA projects. Mission planners expect to have collected more than 1,000 grains between 2 to 5 nanometers in diameter. Most of the grains will be heterogeneous aggregates of carbonaceous matter, glass, and crystals.

Livermore is part of the Bay Area Particle Analysis Consortium (BayPac) formed to develop regional expertise on interplanetary dust particles. BayPac's members include University of California (UC) at Berkeley, UC Davis, Lawrence Berkeley National Laboratory, and Stanford University. Funding for SuperSTEM—the first of its kind in the world—comes from NASA and

Livermore's Laboratory Directed Research and Development Program. John Bradley, director of the Laboratory's Institute of Geophysics and Planetary Physics, says, "This consortium provides a unique opportunity for a collaboration between universities and national laboratories in the San Francisco Bay Area to work together on a NASA mission."



This image shows the nucleus of Comet Wild 2, taken by the Stardust spacecraft in January 2004.

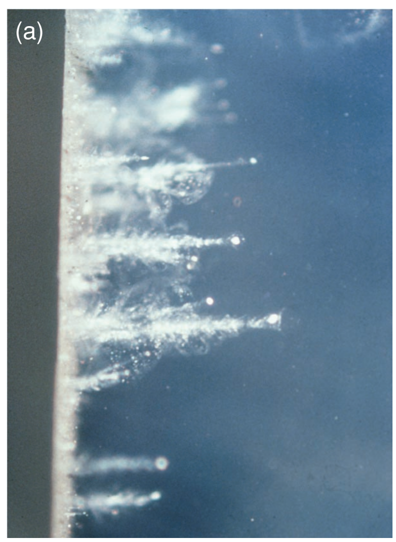
Perfecting Extraction and Analysis Techniques

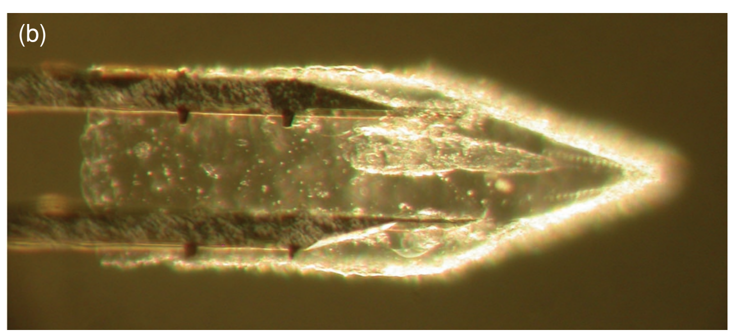
The particles collected by Stardust will be extremely small, so analytical instruments with a spatial resolution of approximately 2 nanometers or less will be needed to focus on the individual grains. Each member of BayPac works on particle manipulation and analysis using a variety of methods and instruments. To study the isotopic compositions of the dust particles, the Livermore team uses the 200-kiloelectronvolt SuperSTEM, which has a 10- to 100-fold resolution increase over other instruments, and its NanoSIMS (nano secondary-ion mass spectrometry), which is one of only two ion microprobes in the U.S. The team also uses a nuclear microprobe that radiates a sample with 3 megavolts of protons to measure its density.

Scientists in the consortium are studying interplanetary dust particles from Russia's Mir Space Station and the International Space Station to refine the extraction techniques they will use on Wild 2 dust. "These particles are perfect analogs to study," Bradley says, "because they were also collected in aerogel, although at a significantly higher speed (11 kilometers per second) than the Stardust collection speed."

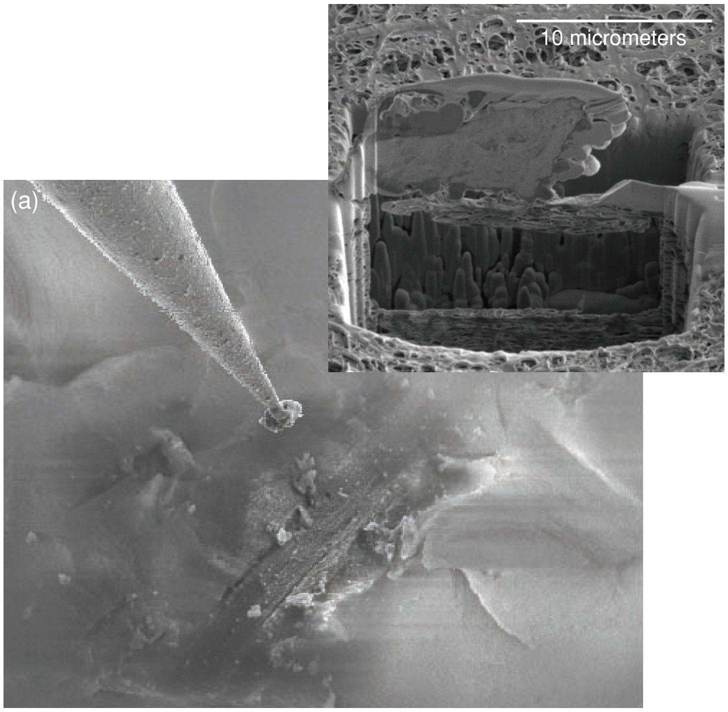
About three years ago, researchers from UC Berkeley's Space Sciences Laboratory developed the "keystone" technique to remove a particle from a sample of aerogel. The term keystone is derived from the tiny wedge that contains the particle track and that is cut out of the aerogel. Detailed optical images of these impact tracks show evidence that particles fragment quite extensively as they project into the aerogel. With the development of the keystone technique, researchers have been able to further refine techniques to remove the fragmented particles. These fine-grained particles must be recovered for comprehensive analysis of cometary material.

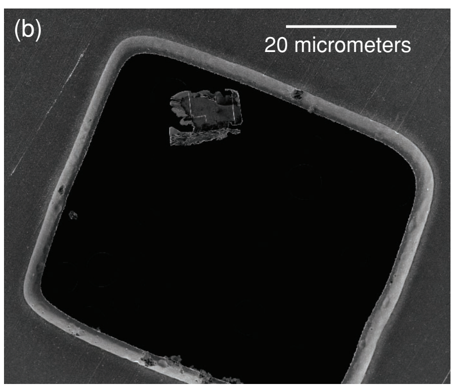
Livermore researchers are determining which method will best remove micrometer- and submicrometer-size particle fragments from the tracks within keystones. Focused-ion-beam microscopy is one promising method being used to extract 0.1-micrometer-thick sections of a particle fragment. The thin sections are then examined using the transmission electron microscope, the NanoSIMS ion microprobe, and synchrotron infrared microscopy. Because the focused-ion-beam method destroys most of the particle fragment, only one or two sections can be harvested from each sample. The advantage of this method is that researchers can extract particles as small as 100 nanometers or less from targeted regions and cut them into thin sections. Livermore scientists take samples from specific





(a) Interstellar dust tracks are shown trapped in a sample of aerogel from a collector grid. (b) The keystone technique allows scientists to extract a fragmented particle from a sample of aerogel. The finer-grain material distributed along the impact tracks must be recovered for comprehensive analysis of comet dust. The technique was developed at the University of California (UC) at Berkeley. (Image courtesy Space Sciences Laboratory, UC Berkeley.)





(a) Focused-ion-beam microscopy is used to extract 0.1-micrometer-thick sections of an interplanetary dust particle from a sample of aerogel (shown in the inset). (b) The thin sections are then examined using the transmission electron microscope.

isotopically anomalous hot spots, that is, areas where the highest concentration of a given isotope is found. Using this approach, researchers can correlate isotope measurements and mineralogy with nanoscale precision.

Preparing for the Return

Scientists worldwide will analyze Wild 2's dust, and many of them will travel to Livermore to use the Laboratory's SuperSTEM. Until then, Livermore will continue to refine extraction and specimen preparation techniques. Bradley notes, "For the first time in 30 years, we will be analyzing returned samples, and Livermore will be busy preparing a large quantity of specimens." In addition to collecting particles, Stardust has an optical navigation camera that has captured images of Wild 2's nucleus. Mission planners were surprised when the first pictures relayed back to Earth showed a large, circular nucleus rather than the expected potato shape seen in comets thus far.

In January 2006, Stardust is programmed to eject its reentry capsule, which will parachute to the Utah desert southwest of Salt Lake City. The much-anticipated return of the capsule will perhaps yield more surprises. Scientists are excited about what Wild 2's dust may reveal about the origins of life on Earth.

—Gabriele Rennie

Key Words: Comet Wild 2, focused-ion-beam microscopy, interplanetary dust particles, nano secondary-ion mass spectrometry (nanoSIMS), Stardust, SuperSTEM (scanning transmission electron microscope).

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Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Low-Cost Method for Producing Extreme Ultraviolet Lithography Optics

James A. Folta, Claude Montcalm, John S. Taylor, Eberhard A. Spiller
U.S. Patent 6,634,760 B2
October 21, 2003
Spherical and nonspherical optical elements produced by standard optical figuring and polishing techniques are extremely expensive. Such surfaces can be inexpensively produced by diamond turning; however, the roughness of diamond-turned surfaces prevents the use of these surfaces for extreme ultraviolet lithography. These ripples are smoothed with a coating of polyimide and the application of a 60-period molybdenum–silicon multilayer to reflect a wavelength of 134 angstroms (13.4 nanometers) and have obtained peak reflectivities close to 63 percent. The savings in cost are about a factor of 100.

Detection of Submicron Scale Cracks and Other Surface Anomalies Using Positron Emission Tomography

Thomas E. Cowan, Richard H. Howell, Carlos A. Colmenares
U.S. Patent 6,693,277 B2
February 17, 2004
Detection of submicrometer-scale cracks and other mechanical and chemical surface anomalies using positron emission tomography (PET). This surface technique has sufficient sensitivity to detect single voids or pits of submillimeter size and single cracks or fissures of millimeter size. This technique can also be applied to detect surface regions of differing chemical reactivity. It may be used in a scanning or survey mode to simultaneously detect such mechanical or chemical features over the interior or exterior surface areas of parts as large as about 50 centimeters in diameter. The technique involves exposing a surface to short-lived radioactive gas; removing the excess gas to leave a partial monolayer; determining the location and shape of such features as cracks, voids, and porous regions; and then calculating the width, depth, and length thereof. Detection of 0.01-millimeter-deep cracks using a 3-millimeter detector resolution has been accomplished with this technique.

Phased Laser Array for Generating a Powerful Laser Beam

John F. Holzrichter, Anthony J. Ruggiero
U.S. Patent 6,693,943 B1
February 17, 2004
A first injection laser signal and a first part of a reference laser beam are injected into a first laser element. At least one additional injection laser signal and at least one additional part of a reference laser beam are injected into at least one additional laser element. The first part of a reference laser beam and the additional part or parts are amplified and phase-conjugated to produce a first amplified output laser beam emanating from the first laser element and an additional amplified output laser beam emanating from the additional element (or elements). The first amplified output laser beam and the additional amplified output laser beam are combined into a powerful laser beam.

Thiacrown Polymers for Removal of Mercury from Waste Streams

Theodore F. Baumann, John G. Reynolds, Glenn A. Fox
U.S. Patent 6,696,576 B2
February 24, 2004
Thiacrown polymers immobilized to a polystyrene–divinylbenzene matrix react with mercury^{2+} under various conditions to efficiently and selectively remove mercury^{2+} ions from acidic aqueous solutions, even in the presence of a variety of other metal ions. The mercury can be recovered and the polymer regenerated. This mercury removal method can be used to treat industrial wastewater, where a selective and cost-effective removal process is required.

Polymerase Chain Reaction System

William J. Benett, James B. Richards, Paul L. Stratton, Dean R. Hadley, Fred P. Milanovich, Phil Belgrader, Peter L. Meyer
U.S. Patent 6,699,713 B2
March 2, 2004
A portable polymerase chain reaction DNA amplification and detection system includes one or more chamber modules. Each module supports a duplex assay of a biological sample and has two parallel interrogation ports with a linear optical system. The system can be handheld.

High Energy, High Average Power Solid State Green or UV Laser

Lloyd A. Hackel, Mary Norton, C. Brent Dane
U.S. Patent 6,700,906 B2
March 2, 2004
A system for producing a green or ultraviolet (UV) output beam for illuminating a large area with relatively high beam fluence. A neodymium-doped glass laser produces a near-infrared output by means of an oscillator that generates a high-quality but low-power output. The output is then multipassed through and amplified in a zigzag slab amplifier. Wavefront correction occurs in a phase conjugator at the midway point of the multipass amplification. The green or UV output is generated by means of conversion crystals that follow final propagation through the zigzag slab amplifier.

Application of the Phase Shifting Diffraction Interferometer for Measuring Convex Mirrors and Negative Lenses

Gary E. Sommargren, Eugene W. Campbell
U.S. Patent 6,704,112 B1
March 9, 2004
A reference beam and a measurement beam are both provided through a single optical fiber to measure a convex mirror. A positive auxiliary lens is placed in the system to give a converging wavefront onto the convex mirror being tested. The measurement includes the aberrations of the convex mirror and the errors caused by two transmissions through the positive auxiliary lens. A second measurement provides the information to eliminate this error. A negative lens can be measured in a similar way, again with two setups: a reference beam from a first optical fiber and a measurement beam from a second optical fiber. A positive auxiliary lens is placed in the system to provide a converging wavefront from the reference beam onto the negative lens being tested. The measurement beam is combined with the reference wavefront and is analyzed by standard methods. This measurement includes the aberrations of the negative lens and the errors caused by a single transmission through the positive auxiliary lens. A second measurement provides the information to eliminate this error.

Synthetic Guide Star Generation

Stephen A. Payne, Ralph H. Page, Christopher A. Ebbers, Raymond J. Beach
U.S. Patent 6,704,331 B2
March 9, 2004
A system for assisting in observing a celestial object and providing synthetic guide star generation. A lasing system provides radiation at a

frequency at or near 938 nanometers and radiation at a frequency at or near 1,583 nanometers. The lasing system includes a fiber laser operating between 880 and 960 nanometers and a fiber laser operating between 1,524 and 1,650 nanometers. A frequency-conversion system mixes the radiation and generates light at a frequency at or near 589 nanometers. A system then directs this light toward the celestial object and generates a synthetic guide star.

Diode-Pumped Laser with Improved Pumping System

Jim J. Chang
U.S. Patent 6,704,341 B1
March 9, 2004
A laser wherein pump radiation from laser diodes is delivered to a pump chamber and into the lasing medium by quasi-three-dimensional compound parabolic concentrator light channels. The light channels have reflective side and end walls with curved surfaces. A flow tube between the lasing medium and the light channel has a roughened surface.

Reduction of Damage Initiation Density in Fused Silica Optics Via UV Laser Conditioning

John E. Peterson, Stephen M. Maricle, Raymond M. Brusasco, Bernardino M. Penetrante
U.S. Patent 6,705,125 B2
March 16, 2004
The invention provides a method for reducing the density of sites on the surface of fused silica optics that are prone to the initiation of laser-induced damage. This reduction results in optics that have far fewer catastrophic defects and can better resist optical deterioration when exposed for long periods to a high-power laser beam having a wavelength of about 360 nanometers or less. The initiation of laser-induced damage is reduced by conditioning the optic at low fluences below levels that normally lead to catastrophic growth of damage. When the optic is then irradiated at its high fluence design limit, the concentration of catastrophic damage sites that form on the surface of the optic is greatly reduced.

Lightweight Cryogenic-Compatible Pressure Vessels for Vehicular Fuel Storage

Salvador Aceves, Gene Berry, Andrew H. Weisberg
U.S. Patent 6,708,502 B1
March 23, 2004
A lightweight, cryogenic-compatible pressure vessel for flexibly storing cryogenic liquid fuels or compressed gas fuels at cryogenic or ambient temperatures. The pressure vessel has an inner pressure container enclosing a fuel storage volume, an outer container surrounding the inner pressure container to form an evacuated space between the two, and a thermal insulator surrounding the inner pressure container in the evacuated space to inhibit heat transfer. Additionally, vacuum loss from fuel permeation is substantially inhibited in the evacuated space by, for example, lining the container liner with a layer of fuel-impermeable material, capturing the permeated fuel in the evacuated space, or purging the permeated fuel from the evacuated space.

Method for Removing Organic Liquids from Aqueous Solutions and Mixtures

Lawrence W. Hrubesh, Paul R. Coronado, Jerome P. Dow
U.S. Patent 6,709,600 B2
March 23, 2004
A method for removing organic liquids from aqueous solutions and mixtures. The method uses any porous material preferably in granular form and having small pores and a large specific surface area. The surface area is hydrophobic so that liquid water does not readily wet its surface. In this method, organics, especially organic solvents that mix with and are more volatile than water, are separated from aqueous solution by preferential evaporation across the liquid–solid boundary formed at the surfaces of the hydrophobic porous materials. Also, organic solvents that are immiscible with water preferentially wet the surfaces of the hydrophobic material and are drawn within the porous materials by capillary action.

Awards

Mark Martinez has been selected **Professional of the Week** by the **Hispanic Engineer National Achievement Awards Conference (HENAAC).** Martinez recently became deputy program leader for the Nevada Experiments and Operations Program in the Defense and Nuclear Technologies Directorate and has served as test director for the JASPER (Joint Actinide Shock Physics Experimental Research) Facility. The facility houses a new two-stage gas gun used to determine the properties of plutonium at high pressures, temperatures, and strain rates. (See the article on p. 4.) Martinez managed the building and start-up operations for the JASPER Facility, which included meeting all governmental regulations and policies, managing the program for high-pressure plutonium experiments, and coordinating multidisciplinary teams of scientists and engineers from the Laboratory and other agencies.

The HENAAC was established in 1989 to identify, honor, and document the contributions of outstanding Hispanic-American professionals working in the fields of science, engineering, and technology. Corporations, government agencies, academic institutions, the military, and the business community-at-large have submitted thousands of nominees over the last 14 years for this prestigious recognition.

Shocking Plutonium to Reveal Its Secrets

The Joint Actinide Shock Physics Experimental Research (JASPER) Facility is located at the Department of Energy's Nevada Test Site (NTS). Since July 2003, the facility's 30-meter-long, two-stage gas gun has been obtaining data on the properties of plutonium under extreme pressures and temperatures. The gas gun fires a projectile weighing 30 grams and traveling up to 8 kilometers per second. The projectile impacts an instrumented target of about 30 grams of plutonium. The results from the gas-gun experiments are strengthening scientists' ability to determine the safety and reliability of the nation's nuclear stockpile. Livermore operates JASPER for the National Nuclear Security Administration. Plutonium targets, which must meet extremely precise manufacturing requirements, are produced at Livermore and then transported to NTS.

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Strategic Supercomputing Comes of Age

Nearly a decade ago, the Department of Energy directed the nation's three nuclear weapons laboratories to create new supercomputing capabilities for meeting the needs of the nation's nuclear stockpile. The Accelerated Strategic Computing Initiative (ASCI) was begun because scientists needed to analyze and predict the safety, reliability, and performance of the nation's nuclear weapons and certify their functionality in the absence of nuclear weapons testing. This new focus required creating a unique supercomputing capability on all fronts: hardware; computing infrastructures; and scalable, high-fidelity, three-dimensional simulation codes. Today, that effort is no longer an initiative, and the Advanced Simulation and Computing (ASC) Program prepares to move into a new phase where physics takes center stage. Materials properties research, for instance, is entering a period in which material behavior can be predicted from first principles with terascale machines and their codes. ASC simulations are playing a key role in stockpile certification and nuclear-weapon life extension programs. The 100-teraops ASC Purple machine, arriving at Livermore in 2005, is the entry point for running a full-system calculation of a nuclear weapon with sufficient resolution to distinguish between phenomenological and numerical issues. The goal is to predict weapons behavior and quantify the confidence scientists have in that prediction.

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U.S. Government Printing Office: 2004/683-056-70062

Protecting Water at the Source

A major research initiative at Livermore is helping California manage its future supply of freshwater.

Also in July/August

- *Laboratory researchers are going to extremes to understand chemical reactions under intense pressures and temperatures.*

- *A self-contained nuclear reactor is designed to be tamper resistant and transportable to anywhere in the world.*

- *A new instrument tracks the velocity of exploding materials by measuring beat frequencies.*

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